國 立 交 通 大 學

運輸與物流管理學系

博士論文

No.008

機場空側風險管理

Airport Airside Risk Management

研 究 生：鍾啟椿

指導教授：馮正民　博士

中 華 民 國 一 〇 四 年 二 月

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機場空側風險管理

Airport Airside Risk Management

研究生： 鍾啟椿 Student： Chi-Chun Chung
指導教授： 馮正民 博士 Advisor： Dr. Cheng-Min Feng

國 立 交 通 大 學

運輸與物流管理學系

博 士 論 文

A Dissertation

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in

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論文題目：機場空側風險管理

指導教授：馮正民

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系 主 任： 教授

中 華 民 國 一〇四 年 二 月 十二 日

A DISSERTATION OF Chi-Chun Chung

ENTITLED Airport Airside Risk Management

WAS ACCEPTED AS PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

Committee

Dissertation Advisor

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機場空側風險管理

研究生：鍾啟椿　　　　　　　　　　　　　　　　　指導教授：馮正民 博士

國立交通大學運輸與物流管理學系博士論文

摘要

任何的飛安事故皆可能導致令人無法逆料的致命損失，且經統計有近八成的意外發生在機場。因此，如何有效的識別飛安風險，進而客觀的衡量其風險值並建立相關風險評估矩陣將是機場安全管理的首要之務。而建立系統性的機場風險管理機制以有效的監管和改善飛安風險，亦為降低飛安潛在風險並實現機場安全目標的唯一途徑。

為有效達成上述目標，本研究先從國際民用航空組織(International Civil Aviation Organization: ICAO)的航空事故資料庫中萃取與機場相關的風險因子及飛航程序，並以失效模式、影響和危害性分析(Failure Modes, Effect and Criticality Analysis: FMECA)中指數型風險優先數(Risk Priority Numbers: RPN)的定義，將風險事件發生的頻率、嚴重度和可偵測程度定為決策因子，再運用模糊邏輯控制(Fuzzy Logic Control: FLC)模式，推導出模糊規則並衡量各風險項目之風險優先數，進而推估出各決策因子權重、建立風險評估矩陣(Risk Assessment Matrix: RAM)及決定各風險門檻值。本研究並以臺灣桃園國際機場(Taiwan Taoyuan International Airport: TTIA)為例，進行風險分析找出該機場不可接受的風險項目，以驗證上開模式之適用性。

最後，為有效降低上開風險可能對 TTIA 造成的危害，本研究參考 ICAO、行政院飛航安全委員會、民用航空局及桃園國際機場公司等飛安風險管理相關文件，就管理面、營運面及設施面研擬出各項風險對應之改善措施，並運用品質機能展開模式(Quality Function Deployment: QFD)的概念進行方案排序，期能在資源有限的情況下逐步推動風險改善方案。本研究已驗證上開風險管理模式之適用性及可及性，希望能提供機場管理者一個有效且系統性的風險管理決策參考。

關鍵詞：機場風險、模糊邏輯控制、風險改善措施、風險衡量、品質機能展開模式

Airport Airside Risk Management

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ABSTRACT

Any aviation accident may lead to unpredictable fatal losses. Statistically, approximately 80% of aviation accidents occur at airports. Therefore, how to identify risk items, measure risk values objectively and establish the Risk Assessment Matrix of airports is a major task for airport safety management. Establishing a risk management mechanism for airports to monitor and reduce these risks is the only solution to lower latent risks efficiently and to achieve the goal of airport safety.

To identify risk items, measure risk values objectively and establish the Risk Assessment Matrix (RAM) of airports is the major task of airport safety. This research first extracts 14 risk items of airports from the International Civil Aviation Organization (ICAO) aviation accidents database and then applies Failure Modes, Effect and Criticality Analysis (FMECA) to define the decision factors of Possibility, Severity and Detectability of airport risks. This research also designs a questionnaire and applies Fuzzy Logic to discover the importance of decision factors, to find out the threshold value of RAM to prioritize the airport risks. This research u ses Taiwan Taoyuan International Airport (TTIA) as a case study to demonstrate the modeling process and analyze the results.

Finally, referring to the related safety management manuals and documents of ICAO, Aviation Safety Council, Civil Aeronautics Administration and Taoyuan International Airport Company, this research proposes some related improvement measures, using the concept of Quality Function Deployment (QFD) model to prioritize those proposed measures. It is hoped that the results can be beneficial to reduce the TTIA airside risks efficiently. And we also hope that this risk management model can be applied to assist airport operator in implementing risk improvement programs systematically.

Keywords: Airport Risk, Fuzzy Logic Control, Improvement Measures, Risk Assessment, Quality Function Deployment

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A special thanks to my family. Words cannot express how grateful I am to my father, mother for all of the sacrifices that you've made on me. Your prayer for me was what sustained me thus far. As to my two lovely sons, your laughters transform into the power to encourage me to go forward.

At the end, I would like to express appreciation to my beloved wife Hao-Ping Wen who spent sleepless nights with and motivated me to strive towards my goal.

I do solemnly dedicate this to my beloved wife.

Chi-Chun Chung

12 February 2015

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CHAPTER 1. INTRODUCTION

1.1 Background and Motivation

Ever since the invention of airplanes, aviation safety has been one of the most important aspects of flight. Air transportation is far more flourishing worldwide nowadays. Even though the probability of an aviation accident is very low (Janic, 2000), and according to International Civil Aviation Organization (ICAO) statistics (ICAO, 2013), world aviation related accidents have gone down over the years and stablelizing at 0.7 accidents per million flights. Nevertheless, any aviation accident may lead to unpredictable fatal losses. According to the safety report of International Air Transportation Association (IATA), fifty-eight percent of all accidents occurred on the runway in the airport airside from 2009 to 2013 and the most frequent type is runway excursion (IATA, 2014). These accidents in the airport airside have caused the severe loss of lives, aircraft crashes, and property damages. Statistically, approximately 80% of aviation accidents occur at airports. There are numerous aviation accidents happened in the past. Each one leaded to serious loss of life and wealth. Here take some examples as follows.

American Airlines Flight 191 was a regularly scheduled passenger flight from O'Hare International Airport in Chicago to Los Angeles International Airport. The McDonnell Douglas DC-10-10 crashed on May 25, 1979, moments after takeoff from Chicago. All 258 passengers and 13 crew members on board were killed, along with two people on the ground. It is the deadliest aviation accident to have occurred in the United States (NTSB, 1980). Ten years later, United Airlines Flight 232 was a scheduled flight from Stapleton International Airport in Denver, Colorado, to O'Hare International Airport in Chicago. On July 19, 1989, the DC-10 operating the route crash-landed in Sioux City, Iowa, after suffering catastrophic failure of its tail-mounted engine, which led to the loss of all flight controls and 111 died in the accident on board (NTSB, 1991).

Fifty years later, Flash Airlines Flight 604 was a charter flight operated by Egyptian charter company Flash Airlines. On 3 January 2004, the Boeing 737-300 crashed into the Red Sea shortly after takeoff from Sharm el-Sheikh International Airport, killing all 135 passengers and 13 crew members. The findings of the crash investigation are controversial, with accident investigators from the different countries involved not agreeing on the cause. The death toll is the highest of any aviation accident in Egypt and involving a Boeing 737-300 (Egypt Ministry of Civil Aviation, 2005).

Although some above-mentioned aviation accidents happened in non-airport areas, some accidents also terribly just occurred in the airport field. For example, Southwest Airlines flight 1248 departed from Baltimore/Washington International Thurgood Marshall Airport, Baltimore, Maryland ran off the departure end of runway 31C after landing at Chicago Midway International Airport, Chicago, Illinois. On December 8, 2005, the Boeing 737-7H4 rolled through a blast fence, an airport perimeter fence, and onto an adjacent roadway, where it struck an automobile before coming to a stop. A child in the automobile was killed, one automobile occupant received serious injuries, and three other automobile occupants received injuries. Eighteen of the 103 airplane occupants received injuries as well, and the airplane was substantially damaged (NTSB report, 2007).

Another case is that East Coast Jets flight 81 was a nonscheduled, domestic passenger flight operating under the provisions of 14 Code of Federal Regulations Part 135. On July 31, 2008, the Hawker Beechcraft Corporation 125-800A airplane crashed while attempting to go around after landing on runway 30 at Owatonna Degner Regional Airport, Owatonna, Minnesota, two pilots and six passengers were killed, and the airplane was destroyed by impact forces. An instrument flight rule of flight plan had been filed and activated; however, it was canceled before the landing. Visual meteorological conditions prevailed at the time of the accident (NTSB report, 2011).

As what were mentioned above, aviation or airport accidents always cause serious loss of life and wealth. The airport accidents may lead to the interruption of airport operation as well. Considering that the need for airport safety is paramount, ICAO published the ICAO Safety Management Manual (SMM), Third Edition (Doc 9859-AN/474) in 2013 (ICAO, 2013), intended to serve as a source of information and guidance on safety management. Furthermore, for providing States with guidance on the development and implementation of a State Safety Programme (SSP), ICAO incorporate SSP provisions into Annex 19 - Safety Management. For the undertaking of Taiwan's aviation safety, Taiwan Civil Aeronautics Administration (CAA) follows aforementioned ICAO regulations to establish the safety management system (SMS) as well as implemented them in related civil aviation laws and regulations.

The management of an airport takes a complex system, and each facility in the airport is an important component of the system. Any component influences the airport operation to some extent and may lead to aviation accidents if it fails. The airport operator must keep the aviation risks under an acceptable level considering a limited budget resource. The prioritization of improvement measurements should be based on reasonable risk level. However, most of past researches in aviation safety focused on the ambient medium of aircraft operation (Kern, 1996), air traffic control system (Barnett *et al.*, 1979), airline finance (Rose, 1990 and Singal, 1998), crew management (Helmreich *et al.*, 2001), aviation safety system of airlines organization and culture (Wong and Yeh, 2003), and logistics issues such as apron operation and security check, less attention has been paid on airport risk management (Yang, 2004). Not to mention that each airport in different area has its own specific characters related with its original inside/outside environment and circumstance. Different airports confront different risk situation and must implement suitable improvement measures, while all facing the same budgetary dilemma. Therefore, a systematic procedure to analyze and quantify the airport risks is necessary.

According to Civil Aviation Policy White Paper (CAA, 2000), our national aviation safety system is comprised of CAA, ASC (Aviation Safety Council), airport corporation, airlines, civil aviation group, civilian and military. The CAA and airport corporation are especially important because they are in charge of air safety control, command and provide relevant air traffic infrastructure. Thus, they are the most important parts of aviation safety. Nevertheless, our nation's airport safety management still focuses on day-to-day inspection to maintain the smooth operation of air traffic.

Some theories such as Domino Sequence Theory (Heinrich, 1931), Swiss Cheese Theory (Reason, 1997), SHELL Model (Edwards, 1988), and so on are applied to analyze the aviation accidents. While most aviation risk management focused on the discussion of airline, airplane, environment, organization, and so forth (Heinrich, 1931; Edwards, 1988; Boeing Company, 2007; IATA, 2014). Few literatures applied the risk management procedure to analyze and ensure the airport safety. Hence, in order to implement the airport risk management more effectively and systematically, this research attempts to propose a system framework of airport risk management. Our motivation in this research is produced by trying to resolve the following issues below.

1. How to identify and assess the airport airside risks (risk item/failure mode) under the condition of only few cases?

2. How to construct and decide the risk assessment matrix (RAM) threshold value objectively?

3. How to evaluate the importance of each risk decision factor?

4. How to explore the serious risk items, dangerous areas and risky flight operation procedures?

5. How to propose and prioritize the improvement measures?

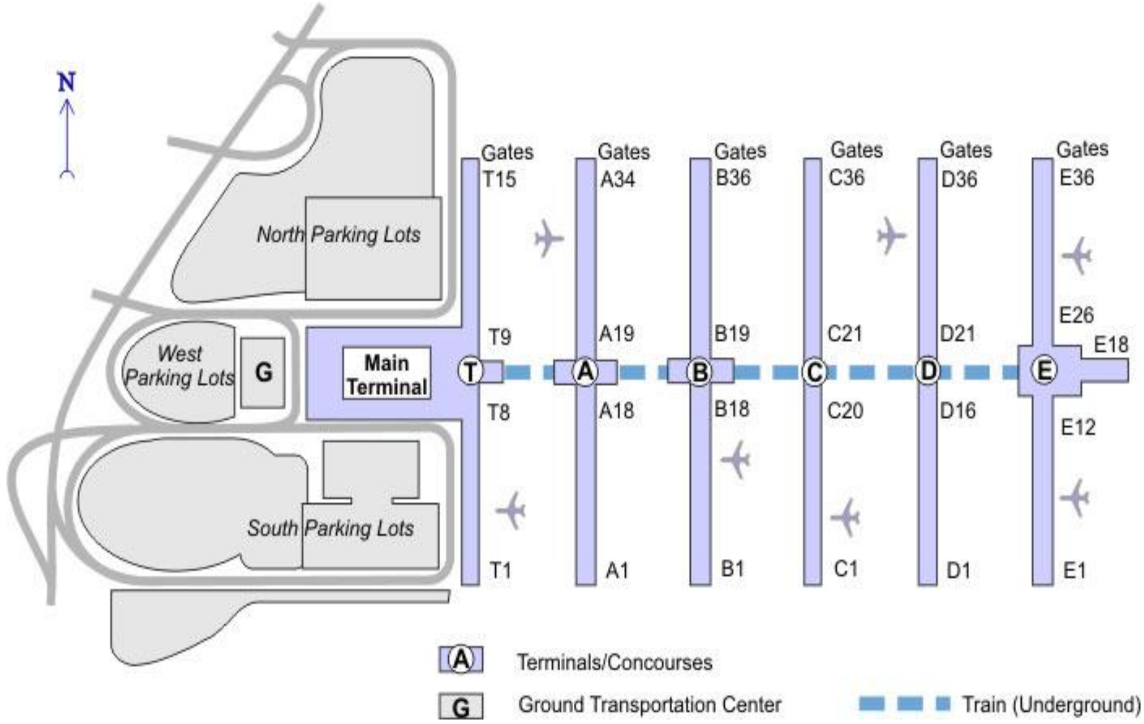
In summary, the airport safety is of paramount importance in aviation safety field, while past literature reviews show that less attention has been paid on it. And we also lack a systematic procedure to analyze and quantify the risk involved in airport airside objectively for the very low probability of an aviation accident. To remedy for the research gap above-mentioned, this study focuses on finding a systematic process and building a system framework to analyze and quantify the airport airside risks from the airport operator's point of view. Filling this research gap could help airport operators build a systematic framework to assess the airport airside risks and provide them the improvement measures.

1.2 Research Scope

The aviation safety system is extremely complex. Other than external factors, there are airport, passenger and airlines to consider. This study stays within the framework of understanding the risks involved with the operation of an airport, including airport airside areas, related flight procedures and risk items.

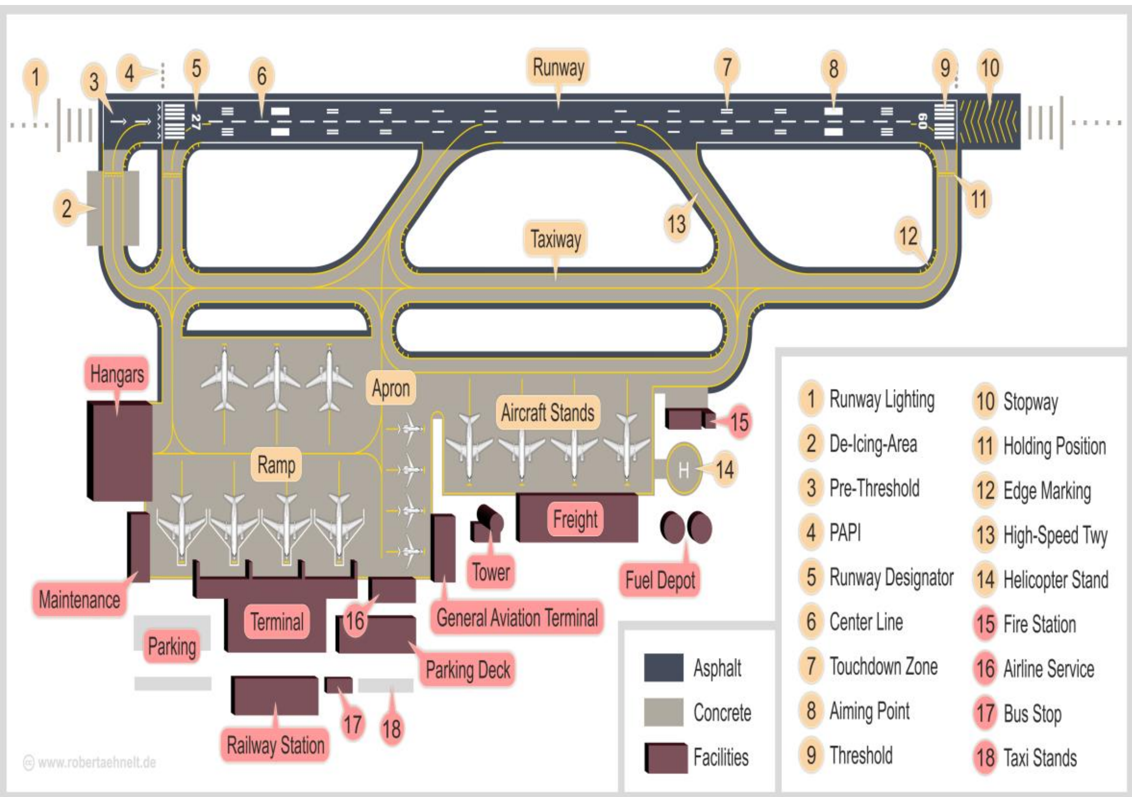
1.2.1 Airport airside areas

An airport is a location with facilities for military aircraft, helicopter or commercial aviation flights to take off and land. Airports often have facilities to store and maintain various types of aircrafts. An airport consists of landing areas, control towers, hangars and terminals. Larger airports may even have fixed base operator services, airport aprons, and air traffic control centers, passenger facilities such as restaurants and lounges, and emergency services. International airports have additional facilities for customs and immigration. In general, airports are divided into landside and airside areas. Landside areas contain parking lots, public transportation train stations and access roads. Airside areas include all areas accessible to aircraft, including runways, taxiways and ramps. Access from landside areas to airside areas is tightly controlled at most airports. Take Hartsfield-Jackson Atlanta International Airport as an example showed in Figure 1.1 and Figure 1.2 to illustrate the airside infrastructures.



Source: Hartsfield-Jackson Atlanta International Airport, 2014.

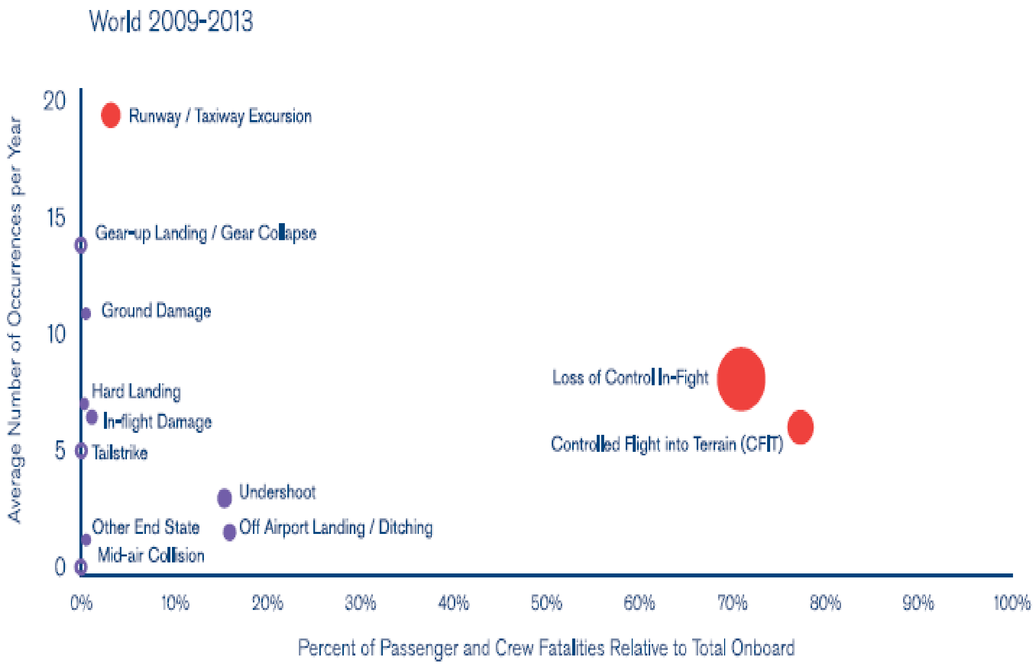
Figure 1.1 Hartsfield-Jackson Atlanta International Airport



Source: Hartsfield-Jackson Atlanta International Airport, 2014

Figure 1.2 Airside Infrastructures

The international Air Transport Association (IATA) has introduced the concept of high-risk accident categories in its Safety Report 2013（2014）. This is designed to expand beyond the traditional methods of high frequency as a single metric for prioritization of mitigation efforts and incorporate with a metric for accident outcome related to survivability. Figure 1.3 shows that each accident category is plotted by the average number of occurrences per year and the percentage of fatalities relative to the total number of people on board. The bubble size increases as the absolute number of fatalities for the category increases; empty bubbles indicate no fatalities for that accident category. Most Controlled Flight into Terrain (CFIT) accidents occur in the approach and landing phases of flight and are often associated with lack of precise approaches. There is a correlation between the lack of Instrument Landing Systems (ILSs) or state-of-the-art approach procedures, such as Performance-Based Navigation (PBN) and CFIT accidents. While the most frequent type of accident is runway excursion, improving runway safety is a key focus of the industry's strategy to reduce operational risk.



Source: IATA Safety Report 2013, 2014.

Figure 1.3 IATA Accident Chart

According to the above-mentioned analysis, most serious accidents have been occurred in airport airside that will be investigated and discussed in this research. Figure 1.4 shows the flowchart of basic airport operations. According to Figure 1.4, we can see basic airport operation that includes airside, terminal and landside. This study focuses on the risk analysis and improvement in the airport airside area which includes holding pad, apron-gate, taxiway, runway and terminal airspace.

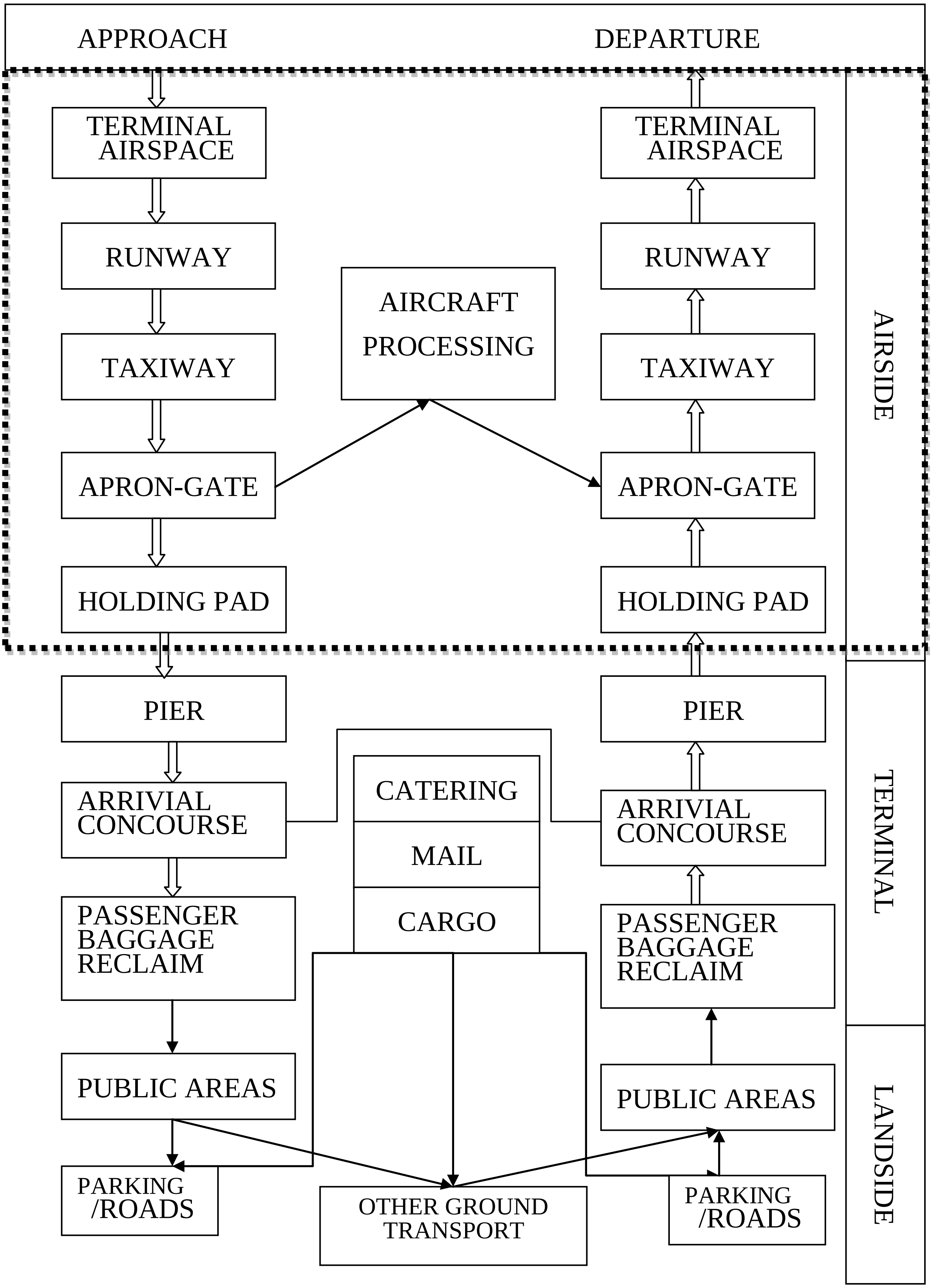
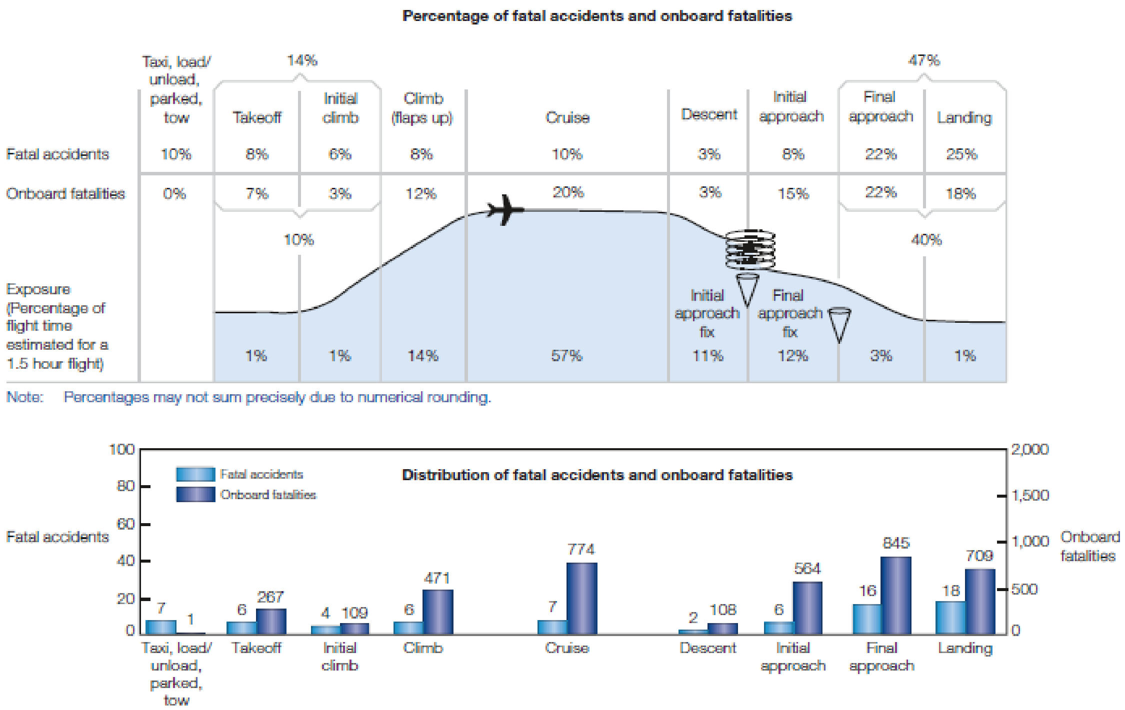


Figure 1.4 Basic Airport Operations.

1.2.2 Flight procedures

Aviation safety is of paramount importance in the operation of an airport. There are many potential risks like bird strikes or adverse weather and so forth that could cause various hazards in an airport. For example, pursuing a vast area to afford aircraft operation, many airports are built near open fields or wild land that are the natural habitats for some wild animals or birds, which can pose a risk to aircraft in the form of animal incursion or bird strikes. In addition, an airport can have areas where collisions between aircraft on the ground tend to occur. For instance, any aircraft or vehicle is in an inappropriate location, could be identified as risky "hot spots" which must undergo special attention by transportation authorities (such as the CAA in Taiwan) and airport administrators.

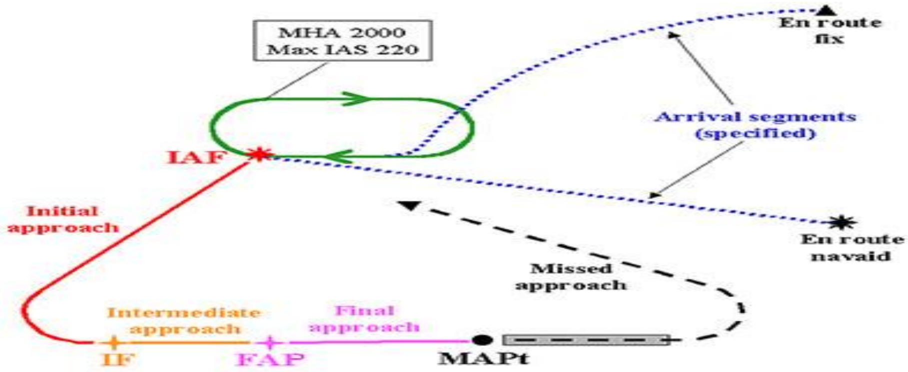
The phases of flight defined by the joint Commercial Aviation Safety Team/ICAO Common Taxonomy Team are Standing (STD), Taxi (TXI), Take off (TOF), Visual flight rules (VFR), Emergency descent (EMG), Uncontrolled descent (UND), Post-impact (PIM), Pushback/Towing (PBT), Initial climb (ICL), En route (ENR), Maneuvering (MNV), Approach (APR), Landing (LDG) and Unknown (UNK). Most of them are associated with the airport except ENR and MNV. Figure 1.5 shows the accidents and fatalities by phase of flight. Over half of all accidents occur during the TOF, ICL, APR and LDG stages. Fatal accidents are more likely to occur during the climbing stage. Most accidents and fatalities take place during the departure (TOF/ICL) and arrival (APR/LDG) stages. During these phases aircraft are close to the ground and in a more vulnerable configuration than during other flight phases. From the fourteen flight procedures described above, STD, PBT, TXI, TOF, APR and LDG are the six procedures that this research will be mainly discussing.



Source: Statistical Summary of Commercial Jet Airplane Accidents, 1959-2013, Boeing, 2014.

Figure 1.5 Fatal Accidents and on Board Fatalities by Phase of Flight

With regard to the airport, instrument approach is a series of predetermined maneuvers for the orderly transfer of an aircraft under instrument meteorological conditions from the beginning of the initial approach to a landing, or to a point from which a landing may be made visually. An instrument approach procedure may contain up to four separate segments-initial, intermediate, final and missed approaches. Each phase is of interlocking and crucial to the airport airside safety. Figure 1.6 shows the instrument approach segments.



Source: ICAO database, 2000.

Figure 1.6 Instrument Approach Segments

1.2.3 Risk items

ICAO Accident Indent Data Reporting (ADREP) 2000 Taxonomy (2010) is a compilation of attributes and the related values. According to ICAO aviation accidents database, aviation risks are categorized into twenty-eight categories including ARC, ADRM, ATM, CFIT, F-NI, RAMP, GCOL, ICE, LOC-G, RE, RI-A, RI-VAP and SEC (ICAO, 2011). This research will only study risk items related to the operation of an airport, since each airport has different external conditions such as geography and weather conditions. Possible risk items involved will be different, and will be looked into case by case in TTIA case studies.

1.2.4 Summary

In summary, this research will be focused on airport airside related flight procedure and possible risk item that happens in the airport airside area. Then, we factor the three dimensions of flight procedure, airside area and risk items to find possible risky scenarios. Finally, we analyze the risky scenarios to come up with improvement measures, and furthermore decide on the priority of the improvement measures.

1.3 Research Objectives

Overall, recognizing that aviation safety is paramount, how to assess the airport airside risks and prioritize those improvement measures systematically are the foremost objectives in this research. In order to analyze and manage airport airside risks effectively, this research attempts to propose a systematic framework of airport airside risk management. By using this framework, this research attempts to conduct risk analysis and management, in order to resolve those issues mentioned in section 1.1. Five primary objectives are devised to address those different specific issues above-mentioned in this research, and these are introduced below.

1. Identify the airport airside risks.

2. Develop a system framework to analyze/quantify the airport airside risks and calculate the importance of each risk decision factor.

3. Construct the RAM and find out the threshold value of risk levels.

4. Propose some related improvement measures to eliminate down risks to the approved level.

5. Analyze and prioritize those proposed improvement measures.

This research tries to resolve those primary issues by achieving above-mentioned objectives through some partial applications of methodologies. To explicate the way to resolve the above-mentioned issues and their corresponding objectives more clearly, Table 1.1 shows their relationships. These methods employed in this research will be discussed in the following chapters in detail.

Table 1.1 Methodologies between Issues and Objectives

Issues	Methodologies	Objectives
How to identify and assess the airport airside risks (risk item/failure mode) under the condition of only few cases?	Literature review and in-depth interviews	Identify the airport airside risks.
	Fuzzy logic-based FMECA (Failure Modes, Effect and Criticality Analysis)	Develop a system framework to analyze/quantify the airport airside risks.
How to construct and decide the RAM threshold value objectively?	RPN (Risk Priority Numbers) value of airport airside risks and fuzzy rule conclusions	Construct the RAM and find out the threshold value of risk levels.
How to evaluate the importance of each risk decision factor?	Fitting the RPN value of airport airside risks and their corresponding fuzzy rule conclusions	Calculate the importance of each risk decision factor.
How to explore the serious risk items, dangerous areas and risky flight operation procedures?	Analyze the airport airside risks statistic situation from the RPN value calculated from the fuzzy logic-based FMECA	Develop a system framework to analyze the statistic situation of airport airside risks.
How to propose and prioritize the improvement measures?	In-depth interviews	Propose some related improvement measures to lower down risks to the approved level.
	Concept of QFD (Quality Function Deployment)	Analyze and prioritize those proposed improvement measures.

1.4 Research Organization and Process

Based on the above-mentioned background, motivations, scopes, issues and objectives, this study is hereby organized as follows:

1. Literature review

Chapter 2 briefly reviews related literatures on risk management, aviation risk management, data collection, in-depth interview, risk identification, aviation risk, risk assessment, FMECA, fuzzy logical control, quality function deployment, and so on. The literature review presents the basis of the analysis of this study, the follow-up models and references.

2. Model framework and methods of risk assessment

Chapter 3 illustrates the model framework of this research and presents that this study applies traditional risk management processes which are risk identification, risk assessment and risk control incorporated with systematic risk measurement and project priority methodologies. This chapter then formulates the RPN equation and describes the process of risk assessment in detail. Finally, according to the unacceptable risks which were identified and evaluated in above-mentioned risk assessment process, chapter 5 will propose some responding improvement measures in this study. To make risk control decisions more efficiently, this study applies the concept of QFD to analyze and prioritize those selected improvement measures discussed in chapter 5.

3. Case study of risk assessment

Chapter 4 demonstrates the risk assessment model presented in chapter 3. Taiwan Taoyuan International Airport (TTIA) located in Taoyuan County, is the largest and busiest international airport in Taiwan. This study uses TTIA as a case study to illustrate the applicability of the above-mentioned methodologies.

4. Analysis of improvement measures

Chapter 5 is the analysis of improvement measures. This study extracts some unaccepted risks in TTIA airside, and proposes some concrete improvement measures based on the areas of management, operation and facility accordingly. Finally, this study applies the concept of QFD to analyze and prioritize those deliberate improvement measures for TTIA operators.

5. Conclusions and future studies

Finally, the conclusions and recommendations for future research are presented in chapter 6. After a serious of systematically risk management procedures, this study finds some unacceptable risks in TTIA airside and proposes some improvement measures to ameliorate those potential risks. To ameliorate those aforementioned unacceptable risks more efficiently and immediately, this study also prioritizes those improvement measures. Finally, some directions were proposed as well for further research in the future.

According to the research organization, the research process of this study can be depicted in Figure 1.7.

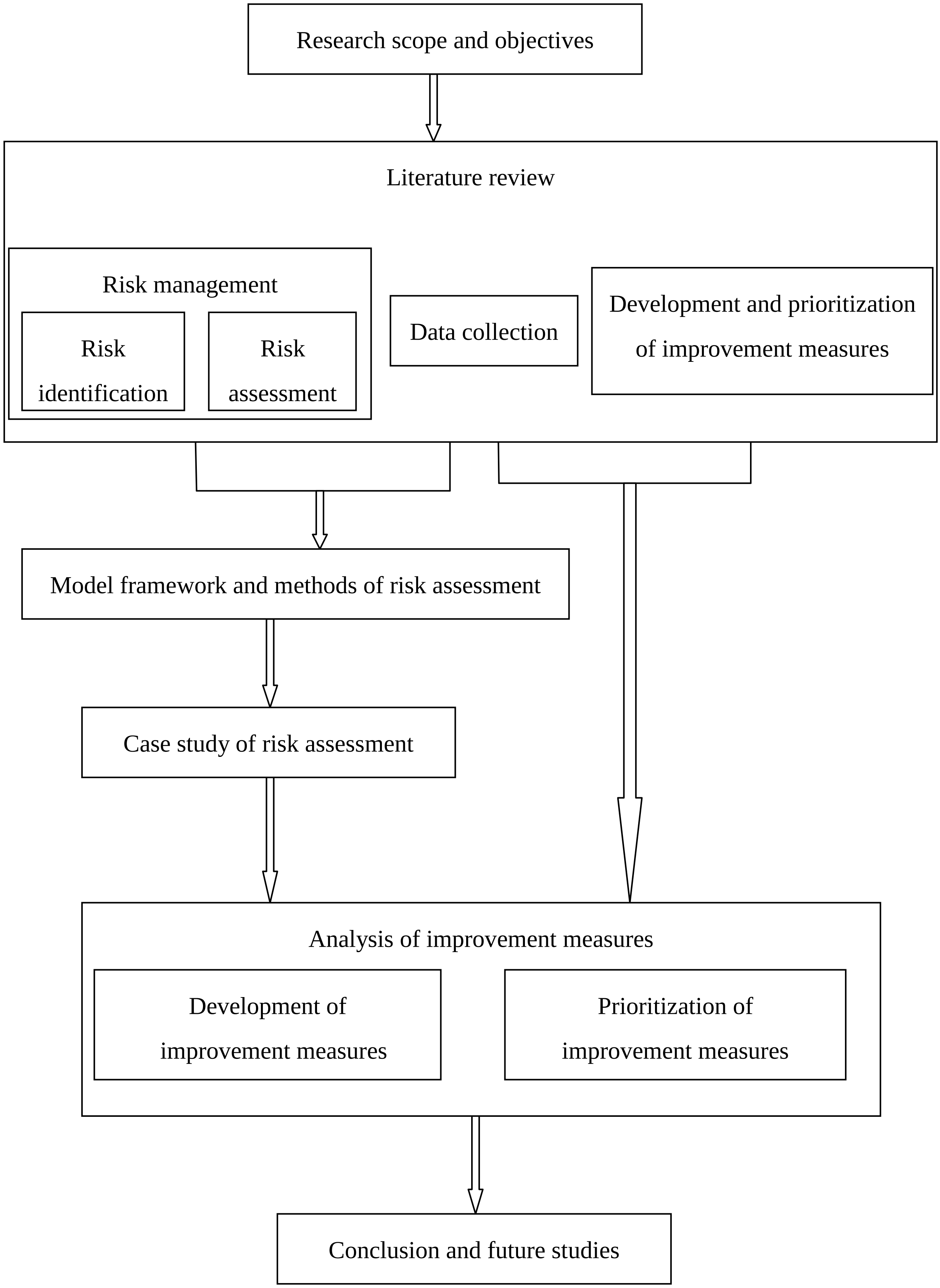


Figure 1.7 Research Process

CHAPTER 2. LITERATURE REVIEW

To reduce the ambiguity and avoid arbitrariness, finding a more objective methodology to transform the subjective experience into objective risk assessment is relatively important. Fuzzy logic based on the experience of experts to describe the severity, frequency of occurrence of the failure, and their fuzzy relationship could be a good method to deal with risk assessment. The methodologies of fuzzy logic control (FLC), failure modes effect and criticality analysis (FMECA) and quality function deployment (QFD) are all processed through the expert in-depth interview to acquire the essential data. Therefore, how to identify risk items, measure risk value objectively and establish the Risk Assessment Matrix for airports is a major task of airport safety management. Establishing a risk management mechanism for airports to monitor and improve these risks is the only solution to lower latent risks efficiently and to achieve the goal of airport safety. This study reviews several related works, including risk management, aviation risk management, data collection, risk identification, risk assessment, development and prioritization of improvement measures. The details of these works are elaborated as follows.

2.1 Risk Management and Aviation Risk Management

2.1.1 Risk management

Risk management is a continuous, systematic decision-making tool to and also one of the methodologies of safety science field. Risk sources are more often identified and located not only in infrastructural or technological assets and tangible variables, but in human factor variables, mental states and decision making. Trevisani (2007) described that it is an extremely hard task to be able to apply an objective and systematic step from the level of the mere "sensation" that something is going wrong, to the clear understanding of how, when and where to act. The truth of a problem or risk is often obfuscated by wrong or incomplete analyses, fake targets, perceptual illusions, unclear focusing, altered mental states, and lack of good communication and confrontation of risk management solutions with reliable partners.

Antunes and Gonzalez (2015) described that risk management’s objective is to assure uncertainty does not deviate the endeavor from the business goals. Risks may come from different adverse events of uncertain or unpredictable root-cause. There are two types of events i.e. negative events can be classified as risks while positive events are classified as opportunities. The strategies to manage threats (uncertainties with negative consequences) typically include transferring the threat to another party, avoiding the threat, reducing the negative effect or probability of the threat, or even accepting some or all of the potential or actual consequences of a particular threat, and the opposites for opportunities (uncertain future states with benefits).

Feng and Chung (2000) proposed an evaluation framework based on risk management, and employed the fuzzy theory and aggregate loss distribution method to analyze the BOT project risks of TTIA. Douglas (2009) defined risk management as the identification, assessment, and prioritization of risks followed by coordinated and economical application of resources to minimize, monitor, and control the possibility and/or impact of unfortunate events or to maximize the success rate. Risks can come from uncertainties in accidents, natural causes, disasters, adverse weather as well as deliberate attacks from events of uncertain or unpredictable root-cause. According to the standard ISO 31000 (Risk management-principles and guidelines on implementation), the process of risk management consists of several steps as follows: establishing the context, identification, assessment, risk options, implementation and review/evaluation of the plan.

2.1.2 Aviation risk management

There are numerous theories that analyze aviation accidents, such as Domino Sequence Theory (Heinrich, 1931). Accident sequence is likened to a row of dominoes knocking each other down and the accident is avoided by removing one of the dominoes, normally the middle one or unsafe act. This theory could infer the happening of the accidents from its outcome, and furthermore discuss the reason that aviation accidents happen and how to improve.

The accident error chain is usually a series of small events that led up the mishap. Willits (2000) and Jeppesen (2004) proposed that in aviation, a chain of events, often called the error chain, is a term referring to the concept that many contributing factors typically lead to an accident, rather than one single event. And these contributing actions typically stem from human factor-related mistakes and pilot error (ICAO, 1993), rather than mechanical failure. A study conducted by Boeing found that 55% of airline accidents between 1959 and 2005 were caused by such human related factors, while only 17% of accidents were caused by mechanical issues with the aircraft (Boeing, 2007). The error chain rule theory described that major aviation accidents happen as a chain of dangerous events, and these dangerous events could be a categorized into crew, flight operations, airplane design/performance, airplane maintenance, aircraft traffic control, airport management and weather information. If we could come up with a system that breaks the chain or network of errors, we could effectively reduce the happening of aviation accidents and improve the aviation safety.

Reason (1997) proposed the Swiss Cheese Theory, it is a model of accident causation used in risk analysis and risk management, including aviation, engineering, healthcare, and as the principle behind layered security, as used in computer security and defense in depth. It likens human systems to multiple slices of Swiss cheese, stacked side by side, in which the risk of a threat becoming a reality is mitigated by the differing layers and types of defenses which are "layered" behind each other. Like the error chain rule theory, lapses and weaknesses in one defense do not allow a risk to materialize, since other defenses also exist, to prevent a single point of weakness. Although the Swiss Cheese Model is respected and considered to be a useful method of relating concepts, Reason *et al.* (2006) discussed some limitation and criticism that it is used over broadly, and without enough other models or support.

Edwards (1988) developed the SHELL model, while Hawkins and Orlady (1993) modified the SHELL model into a “building block” structure. The model is named after the initial letters of its components (software, hardware, environment, liveware) and places emphases on the human being and human interfaces with other components of the aviation system (Johnston et al., 2001). It can be used as a framework for collecting data about human performance and contributory component mismatches during aviation incident/accident analysis or investigation as recommended by the ICAO (2011).

Those theories mentioned above all agree that an accident is not a single event, but originated from a chain of events. These events interlink and influence with each other. If we could eliminate one of the events involved, we could prevent the final events from happening, and thus prevent the accidents. Finally, Matthews (2002) analyzed global aviation accidents and found that on average 4.39 negligence are involved in every accident. For some accidents, the number of negligence can be as many as thirty. This indirectly proved the above mentioned theories that accidents are not caused by simply one event. Thus, current aviation safety management theories all see aviation accident as organizational accident as system accident caused by multiple reasons and errors.

Unlike other transportation modes, the probability of an aviation accident is very low, making it a difficult and complex task to properly explain, locate, and manage overall aviation safety (Janic, 2000). Quantitative assessment of risk is particularly challenging in aviation safety domain where undesired events are extremely rare, and the causal factors are difficult to quantify and non-linearly related (Ahmet and Mehmet, 2012). Feng and Chung (2013) developed a system framework to analyze the airport airside risks through the model of fuzzy logic-based failure modes, effect and criticality.

2.1.3 Summary

Generally speaking, five steps to risk assessment can be followed to ensure the due risk assessment is carried out correctly, these five steps are: identify the hazards, evaluate the risks and decide on control measures, implement the improvement measures, record findings and review the assessment effect. The USA Air Force applied it to implement the operational risk management (ORM) since 1998 consisting of five primary process steps: identify the hazards, assess the hazards, analyze, make control decisions and supervise (Margaret, 2013). Figure 2.1 shows the standardized risk management process “wheel” and associated steps. The final goal of risk management is to propose some effective improvement measures and implement them in order according to their improvement scale priority.

Source: Air Force Pamphlet 90-803, 2013.

Figure 2.1 Air Force Standardized 5-Step RM Process

2.2 Data Collection

Data collection used in the fields of study including physical and social sciences, humanities, business, etc. for capturing quality data is the process of gathering and measuring information on variables of interest, in an established systematic fashion that enables one to answer stated research questions, test hypotheses, and evaluate outcomes. A formal data collection process is necessary as it ensures that data gathered are both defined and accurate and that subsequent decisions based on arguments embodied in the findings are valid (Roger and Victor, 1996). Generally there are three types of data collection include:

1. Surveys: Standardized paper-and-pencil, email or phone questionnaires that ask predetermined questions.

2. Interviews: Structured or unstructured one-on-one directed conversations with key individuals or leaders in a community.

3. Focus groups: Structured interviews with small groups of like individuals using standardized questions, follow-up questions, and exploration of other topics that arise to better understand participants.

Data collection methodology is widely applied in the field of social science research. While the degree of impact from faulty data collection may vary by discipline and the nature of investigation, there is the potential to cause disproportionate harm when these research results are used to support public policy recommendations (Weimer, 1995). The methodologies of data collection may be classified into qualitative and quantitative analysis. Following will review some literatures about methodologies of data collection and in-depth interview.

2.2.1 Methods of data collection

Quantitative methods of sociological research such as questionnaires, personal and telephone interviews etc. are based on interrogating a certain number of respondents and allow for the obtaining of numeric values of the subject of research. They are used most frequently when precise, statistically reliable data are needed and they are always based on strict statistical models, large samplings are used which allows one to find out the quantitative (numeric) values of the indexes that are being researched. Research results are statistically reliable and can be extrapolated on the research target.

On the other hand, qualitative methods of sociological research such as observation, individual and group methods etc. are used to reveal motivation aspects of respondent behavior, personal expectations, notions and values. Unlike quantitative research which is based on statistical procedures, qualitative research has an unstandardized character and it allows free expression of respondents which helps reveal their inherent values and feelings, stimulates their creative potential as well.

Qualitative research is inquiry aimed at describing and clarifying human experience as it appears in people's lives. Burke and Anthony (2004) proposed a mixed methods research (mixed-model designs and mixed-method designs) could be the natural complement to traditional qualitative and quantitative research. They also applied the mixed methods research to prove its methodological pluralism or eclecticism, which frequently results in superior research (compared to monomethod research). Data gathered by using qualitative methods may serve as an evidence for researcher's distilled descriptions. Polkinghorne (2005) proposed that selection of interview participants requires purposive and iterative strategies. Production of interview data requires awareness of the complexity of self-reports and the relation between experience and language expression. To generate interview data of sufficient breadth and depth requires practiced skill and time. Production of useful data from other sources is addressed.

2.2.2 In-depth interview

In-depth interview is a methodology of qualitative research. An in-depth interview is a conversation with an individual conducted by trained staff. The goal of the interview is to deeply explore the respondent's point of view, feelings, personal expectations, notions, values and perspectives. It is aimed at studying a wide range of object's manifestations and do not track its quantitative regularities but rather are oriented at revealing causalities. There are varied types of focus group discussions designed by the research characteristics such as Brainstorming and Delphi. Unlike the group methods, individual methods are executed by specific respondent profiles and in-depth interview is one of the kinds.

The type of interview varies with the interview process and always classified into structured interview, unstandardized interview and semi structured interview. An in-depth interview always comprises unstandardized interviews which are conducted as unconstrained conversations between a moderator and a respondent according to a specific scenario prepared in advanced. There are two main categories of in-depth interviews i.e. standard in-depth interviews and expert in-depth interviews. The standard in-depth interview**s** are taken with respondents selected by certain criteria who are typical representatives of a target audience, while the expert in-depth interviews are taken with people who are specialists on a topic, professionals in a field which is the object of research. Technique choice depends on the purpose of research and, to an extent, on the specifics of respondent profiles.

Interviews are different because the purposes, characteristics and subjects are different. Based on different methods, interviews are categorized based on the level of control during the interview into three types i.e. Standardized Interviews, Unstandardized Interviews and Semi structured Interviews. Semi structured Interviews also named Semi standardized Interviews or Guided Interviews is a method of research used in the social sciences. While a structured interview has a rigorous set of questions which does not allow one to divert, a semi-structured interview is open, allowing new ideas to be brought up during the interview as a result of what the interviewee says. The interviewer in a semi-structured interview generally has a framework of themes to be explored.

George *et al.* (2000) applied the in-depth interviews with purchasing professionals to process the supply risk assessment for minimizing the chance and impact of detrimental events occurring in the supply base. Jukka *et al.* (2002) described a conceptual framework for risk analysis of production networks from the points of view of both a buying company and a supplier through the in-depth interviews.

Irwin and Johnson (2005) proposed that in-depth interviews are used to find deep understanding and information. Researchers have to understand their own research and subject, and attempt to capture and express certain activities, events, and culture. Patton (1990) summarized six types of interviews i.e. experience/behavior, opinion/value, feeling, knowledge, sensory and background. The questioning patterns could be classified as descriptive questioning, structural questioning and contrast questioning.

2.2.3 Summary

This research applies an open and semi standardized interview to proceed with the expert in-depth interview in the analysis of risk assessment and improvement measures for the sake of professionalism and trying to reveal the experts' understanding and knowledge in the airport airside field.

2.3 Risk Identification

Barnett *et al.* (1979) proposed that airline's rate of accidents, are different from the routes, flight distances, airports, air traffic control and aircraft they deploy. Thus, judging an airline by its accident history is unfair, and is not effective in terms of preventing aviation accidents. But Wong and Yeh (2003) proposed that in terms of aviation safety research, accident rate is still the major factor and a widely accepted figure to measure aviation safety by the general public. According to ICAO and Boeing Company's accident statistic definition (ICAO, 2011 and Boeing, 2007), aviation accidents can be categorized into five categories i.e. operational accident, airplane accident (including substantial damage, fatal injury and serious injury), hull loss accident, major partial accident and fatal accident. Following will review some literatures about methodologies of aviation risks and airport airside risks.

2.3.1 Aviation risks

Flight safety is the permanent topic in the field of civil aviation. IATA Safety Report 2013（2014）defines an aviation accident as an occurrence 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 a person is fatally injured or the aircraft sustains damage. It also defines the hazard as the condition, object or activity with the potential of causing injuries to personnel, damage to equipment or structures, loss of material, or reduction of ability to perform a prescribed function.

Heinrich (1931） also classified aviation safety items as human, machine, mission, management, and environment. Edwards （1988）classified them as livewire, hardware, software and environment. Boeing Company（2007）classifies them as crew, airline flight operations, airplane design and performance, airplane maintenance, and weather information. IATA (2014）classifies them as human, organization, machine, environment, and insufficiency.

Airlines are required by law to implement a safety management system for their flight operation as described by the ICAO document (ICAO, 2013). As part of the safety management system, each airport also required to commit itself to a so-called Acceptable Level of Safety Performance (ALoSP). And the ALoSP should be defined in numerical terms for corresponding risk priority numbers (RPN) to judge whether the safety objectives have been achieved.

ICAO aviation accidents data base (ICAO, 2011) classified aviation risks into twenty-eight categories such as ARC, ADRM, ATM, CFIT, F-NI, RAMP, GCOL, ICE, LOC-G, RE, RI-A, RI-VAP and SEC etc. (see Table 2.1).

Table 2.1Aviation Risks and Definitions

Risk	Definition
ARC	Abnormal runway contact (Any landing or takeoff involving abnormal runway or landing surface contact.)
ADRM	Aerodrome (Aerodrome design, service, or functionality issues are evident.)
ATM	Air traffic management (ATM) or communications/navigation/ surveillance (CNS) service issues are evident.
CFIT	Controlled flight into or toward terrain (In-flight collision or near collision with terrain, water, or obstacle without indication of loss of control.)
F-NI	Fire/smoke (non-impact) (Fire or smoke in or on the aircraft, in flight or on the ground, which is not the result of impact.)
RAMP	Ground handling (Occurrences during or from ground handling operations.)
GCOL	Ground collision (Collision while taxiing to or from a runway.)
ICE	Icing (Accumulation of snow, ice, or frost on aircraft surfaces that adversely affects aircraft control or performance.)
LOC-G	Loss of control - ground (Loss of aircraft control while the aircraft is on the ground)
RE	Runway excursion (A veer off or overrun off the runway surface)
RI-A	Runway incursion - animal (Collision with, risk of collision, or evasive action taken by an aircraft to avoid an animal on a runway in use.)
RI-VAP	Runway incursion - vehicle, a/c or person (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.)
SEC	Security related (Criminal/Security acts, which result in accidents or incidents.)
USOS	Undershoot/overshoot (A touchdown off the runway surface.)

Source: ICAO, 2011.

Safety is important to all aviation activities, only proper prevention beforehand can reduce the possibility of accident and loss of lives and money. Barnett *et al.* (1979) proposed that flight route, operation procedure, airport and air traffic control played a great role in the influence of aviation safety. Rose (1990) and Singal (1998) proposed that airline safety is directly proportional to airline profitability. Lin and Chou (2000) applied the Logistic Regression Analysis via the SPSS software to analyze the most risk conditions and factors related to flight accident and to prevent the occurrence of the flight safety accident from the widely collected flight accident investigation statistical data of National Transportation Safety Board (NTSB).

Helmreich et al. (2001) developed a model of flight crew error model to describe the relationship between crew management behaviors, accidents and errors. Lin and Yu (2014) tried to gather all ASC (Aviation Safety Council) domestic airlines accident reports and to analyze all investigation data in order to find and evaluate risks of all factors. Finally, by research and discuss those factors to find ways for future accident prevention. From current papers on aviation safety, aviation risk are discussed mostly based on aviation environment, human organization, hardware or airline, very few are based on specific airports, this could be ineffective in terms of providing improvement measures for specific airports.

2.3.2 Airport airside risks

Daya and Roof (1996) proposed that a risk was traditionally defined as uncertainty or the chance of loss. The uncertainty of event occurrence is subjective and indicates the existence of "whether or not", "when", "circumstance" and "severity". While the loss caused by the occurrence of an event is objective, it emphasizes the possibility of loss (Wang *et al.*, 2009). The definition of risk may be different in research but it always emphasizes the expected value of combining possibility and severity. Detecting risk helps control the occurrence of airport risks during operation. This study introduces detectable concept on airport risk management, and defines "risks" as expected values combining the possibility, severity and detectability.

The International Civil Aviation Organization (ICAO) and the Commercial Aviation Safety Team (CAST), which includes Government official s and aviation industry leaders, have jointly chartered the CAST/ICAO Common Taxonomy Team (CICTT). According to Annex 13 to the Convention on International Civil Aviation Organization, an aviation accident is defined as an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, in which a person is fatally or seriously injured, the aircraft sustains damage or structural failure or the aircraft is missing or is completely inaccessible (ICAO, 2014). Aviation safety is influenced by random factors from human, climate or machinery and all these bring uncertainty.

2.3.3 Summary

An airport system is classified into airside and landside. Airside consists of apron-gate area, taxiway system, holding pad, runway and terminal airspace. Landside consists of terminal buildings and airport ground access system. Accidents on landside may lead to chaos of airport or nearby transportation, while accidents on airside caused not only aircraft damage of staff injury, but also flight schedule delay as well as indirect chaos. This study focuses on airport airside risks. The identification of airport airside risk is the first step of airport risk analysis. Not many literatures identified the airport airside risks and explored specific airport risks so far.

2.4 Risk Assessment

Risk assessment consists of an objective evaluation of risk in which assumptions and uncertainties are clearly considered and presented. It's also the determination of quantitative or qualitative value of risk related to a concrete situation and a recognized hazard (Conrad, 1980). Although Barry (1987) criticized that risk assessment is overly quantitative and reductive for it may ignore qualitative differences among risks drop out important non-quantifiable or inaccessible information. Furthermore, O'Brien (2002) claimed that quantitative approaches divert attention from precautionary or preventative measures. While a proper, suitable and sufficient risk assessment may protect people or poverty from serious injury or loss. There are no fixed rules on how a risk assessment should be carried out, but there are a few general principles that should be followed. This research applies the FLC process and the concept of FMECA to proceed to evaluate the airport airside risk.

2.4.1 Fuzzy logic control

The term “fuzzy logic” was introduced with the proposal of fuzzy set theory by Zadeh (1965). It is a form of multiple-valued logic; it deals with reasoning that is approximate rather than fixed and exact. Novák *et al.* (1999) proposed that compared to traditional binary sets (where variables may take on true or false values); fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Nishant *et al.* (2014) proposed that fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions. Fuzzy logics had, however, been studied since the 1920s and has been applied to many fields, from control theory to artificial intelligence.

Sushmita and Yoichi (2000) described that fuzzy systems can be broadly categorized into two families. The first includes linguistic models based on collections of IF–THEN rules, whose antecedents and consequents utilize fuzzy values. It uses fuzzy reasoning and the system behavior can be described in natural terms such as the Mamdani-type. The second category such as the Sugeno-type uses a rule structure that has fuzzy antecedent and functional consequent parts. Fuzzy inference systems (FIS) are always developed by using Mamdani-type (Mamdani and Assilian, 1975) and Sugeno-type (Takagi and Sugeno, 1985) fuzzy models. Arshdeep and Amrit (2012) outlined the basic difference between the Mamdani-type FIS and Sugeno-type FIS for air conditioning system. Fuzzy logic control is a control system based on fuzzy logic—a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false, respectively). It is widely used in a machine control. Seiji *et al.* (2002) proposed a predictive fuzzy control system that selects the most likely control rule from a set of control rules. The proposed fuzzy control system is applied to a train automatic stop control system that takes into account passenger comfort, accuracy of a stopgap and running time. Simulation results of this newly developed fuzzy control system indicate that the system can directly adjust system performance as desired in a manner similar to control by a skilled operator and thereby stop the train comfortably and accurately.

Research and development is also continuing on fuzzy applications in software, as opposed to firmware, design, including fuzzy expert systems and integration of fuzzy logic with neural-network and so-called adaptive “genetic” software systems, with the ultimate goal of building “self-learning” fuzzy-control systems (Francis, 2000). Pokorádi (2002) proposed that fuzzy logic is a new mathematical tool to model inaccuracy and uncertainty of the real world and human thinking. He also applied the possibility of use of the fuzzy logic to assess the risk. Although alternative approaches such as genetic algorithms and neural networks can apply just as well as fuzzy logic in many cases, fuzzy logic has the advantage that the solution to the problem can be cast in terms that human operators can understand, so that their experience can be used in the design of the controller.

The probability of an aviation accident is very low, making it a difficult and complex task to properly explain, locate, and manage overall aviation safety（Janic, 2000）. Because of this incomplete information and data uncertainty, the traditional risk assessment ranks the level of risks through risk map based on the subjective experience and risk threshold value（Goossens and Cooke, 1997） is hardly applied in the field of aviation risk management. From the above analysis, we can see that airport risk probability is hard to obtain. Thus this research uses the idea of ambiguous possibility to analyze the risk involved and to resolve the fact that airport risk possibility is hard to obtain. Since the subjective experience involves fuzzy linguistic variables to describe the severity, frequency of occurrence of the failure, and their fuzzy relationship, fuzzy logic based on the experience of experts is a suitable method to deal with risk assessment.

2.4.2 Failure modes, effect and criticality analysis

Risk assessments are classified into 3 types of assessments: qualitative, quantitative, and quasi-quantitative. FMECA has been widely used as a quantitative tool to analyze the safety and reliability of products and processes in a wide range of industries (Chang and Cheng, 2010). In 1960s, NASA concluded it a necessary procedure of space development project. In 1970s, it was applied extensively on defense science and technology of America（MIL-STD-1629A, 1980） and motor process（Qs 9000, 1995）. Bowles and Enrique (1995) first applied the fuzzy theory to process the FMEA risk assessment. Chang and Wen (2010) used the Ordered Weighted Average (OWA) operator to resolve the problem of measurement scale.

Previous literatures show that most research of risk analysis by FMECA was applied in the operational-phase. However, conventional FMECA techniques impose some limitations on problem solving such as being difficult to evaluate linguistic variables and obtain the probability distributions that several failure modes occur simultaneously （Xu *et al.*, 2002）. To overcome the drawbacks of FMECA, a number of approaches have been suggested in the literature (Liu *et al*., 2011). One of them proposed fuzzy risk priority numbers (RPN) to prioritize the failure modes (Wang *et al*., 2009). The RPN analysis of FMECA requires the risk factors of P (probability), S (severity), and D (detectability) for each failure mode. However, the weights for each risk need to be identified. Lee and Chang (2005) proposed that the weight of decision factors (i.e. probability, severity and detectability) can indicate the importance implication of those decision factors.

2.4.3 Summary

Overall, FLC based on the experience of experts is a suitable method to deal with the uncertainty of risk assessment. FMECA combining Failure Modes, Effect Analysis (FMEA) and Criticality Analysis (CA) is a systematic analysis method with a bottom-up pattern. In practice, FMECA risk assessment mainly consists of four methods: Mode Criticality, Criticality Rank, Risk Level and Risk Priority Numbers. However, the RPN method is the most extensively used one to assess risk. This research applies the framework of FMECA and

RPN method to assess airport airside risks by decision factors of possibility, severity and severity.

2.5 Development and Prioritization of Improvement Measures

Dorfman and Mark (2007) concluded that strategies to ease the unacceptable risks typically include transferring the risk, avoiding the risk, reducing the negative effect or possibility of the risk, or even accepting the risk which is inevitable. Once risks have been identified and assessed, all techniques to manage the risk fall into one or more of these four major categories: Avoidance (eliminate, withdraw from or not become involved), Reduction (optimize - mitigate), Sharing (transfer - outsource or insure) and Retention (accept and budget). Ideal use of these strategies may not be possible. Some of them may involve trade-offs that are not acceptable to the organization or person making the risk management decisions. The US Department of Defense, Defense Acquisition University, also calls these categories ACAT, for Avoid, Control, Accept, or Transfer. Risk mitigation measures are usually formulated according to one or more of the following major risk options stated above.

2.5.1 Generation of improvement measures

Aviation risks always resulted from diversified fields. Edwards (1988) first developed the SHELL model, while Hawkins and Orlady (1993) modified the SHELL model into a "building block" structure. The model is named after the initial letters of its components (software, hardware, environment, liveware) and places emphases on the human being and human interfaces with other components of the aviation system (Johnston *et al.*, 2001). It can be used as a framework for collecting data about human performance and contributory component mismatches during aviation incident/accident analysis or investigation as recommended by the ICAO (2011).

Improvement is the process of a thing moving from one state to a state considered to be better, usually through some action intended to bring about that better state. Each airport has to plan a safety improvement program according to its risk characteristic to ensure the aviation safety as possible. Usually, the improvement measures are proposed through the expert interviews. Yen *et al.* (2006) conducted a questionnaire survey to analyze the risk of cabin abnormal incidents and propose improvement measures by interviewing civil aviation experts from government, carriers, and related organizations. Risk improvement is a necessary process of incorporating defenses or preventive controls to lower the severity and/or likelihood of a hazard's projected consequence. Boeing Company planning the accident prevention strategies in categories of crew, airline flight operations, air traffic control, airport management, weather information, airplane design/performance and maintenance.

Specific improvement measures, preventive controls or recovery measures should be put in place to prevent the occurrence of a risk or its escalation into an undesirable consequence. In addition to lowering down the airport airside risk level, how to find out the effective and direct improvement measures is much harder due to its complex diversified root cause. Under the premise that airport airside risks were explored and assessed by the previous study, this research finds out some improvement measures to eliminate the potential risks through both document analyses and in-depth-interview with some airport safety experts. By processing a depth-interview with some field experts, this study proposes out the tailored risk improvement measures related to the specific airport.

2.5.2 Analysis and prioritization of improvement measures - QFD

Quality function deployment (QFD) is a new pioneering technique used in many areas to bring the voice of the customer into technical measures. This technique was first developed in Japan back in 1966 by Adao and was used for the first time in 1972 by Kobe Shipyards of Mitsubishi Heavy Industries Ltd (Sullivan, 1986). Organizations throughout North America have used QFD since 1984, with cross-functional teams and concurrent/simultaneous engineering, and on services, products, and the product development process. Hauser and Clausing (1988) defined that House of Quality (HOQ) is a part of the QFD and it utilizes a planning matrix to relate what the customer wants to how a firm (that produces the products) is going to meet those wants. It looks like a house with a “correlation matrix” as its roof, customer wants versus product features as the main part, competitor evaluation as the porch etc. It is based on “the belief that products should be designed to reflect customers' desires and tastes”. It also is reported to increase cross functional integration within organizations using it, especially between marketing, engineering and manufacturing. In certain industries, such as the automobile industry, QFD use is now practically universal. And as companies such as Toyota and Ford demonstrated the effectiveness of QFD, its use in the software industry became inevitable.

Hauser (1993) proposed that HOQ is a diagram, resembling a house, used for defining the relationship between customer desires and the firm/product capabilities. Akao and Shigeru (1994) originally proposed that QFD is a method to transform qualitative user demands into quantitative parameters, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process. Yoram and Amir (2008) proposed a new method based on a mathematical programming extension of quality function deployment to help the decision making of project resource allocation, planned product quality, target market share, and project risk management. QFD is designed to help planners focus on characteristics of a new or existing product or service from the viewpoints of market segments, company, or technology-development needs. QFD helps transform customer needs (the voice of the customer [VOC]) into engineering characteristics (and appropriate test methods) for a product or service, prioritizing each product or service characteristic while simultaneously setting development targets for product or service (Lampa and Glenn, 1996). QFD is applied in a wide variety of services, consumer products, military needs, and emerging technology products. The technique is also included in the new ISO 9000:2000 standard which focuses on customer satisfaction (Akao and Glenn, 1998).

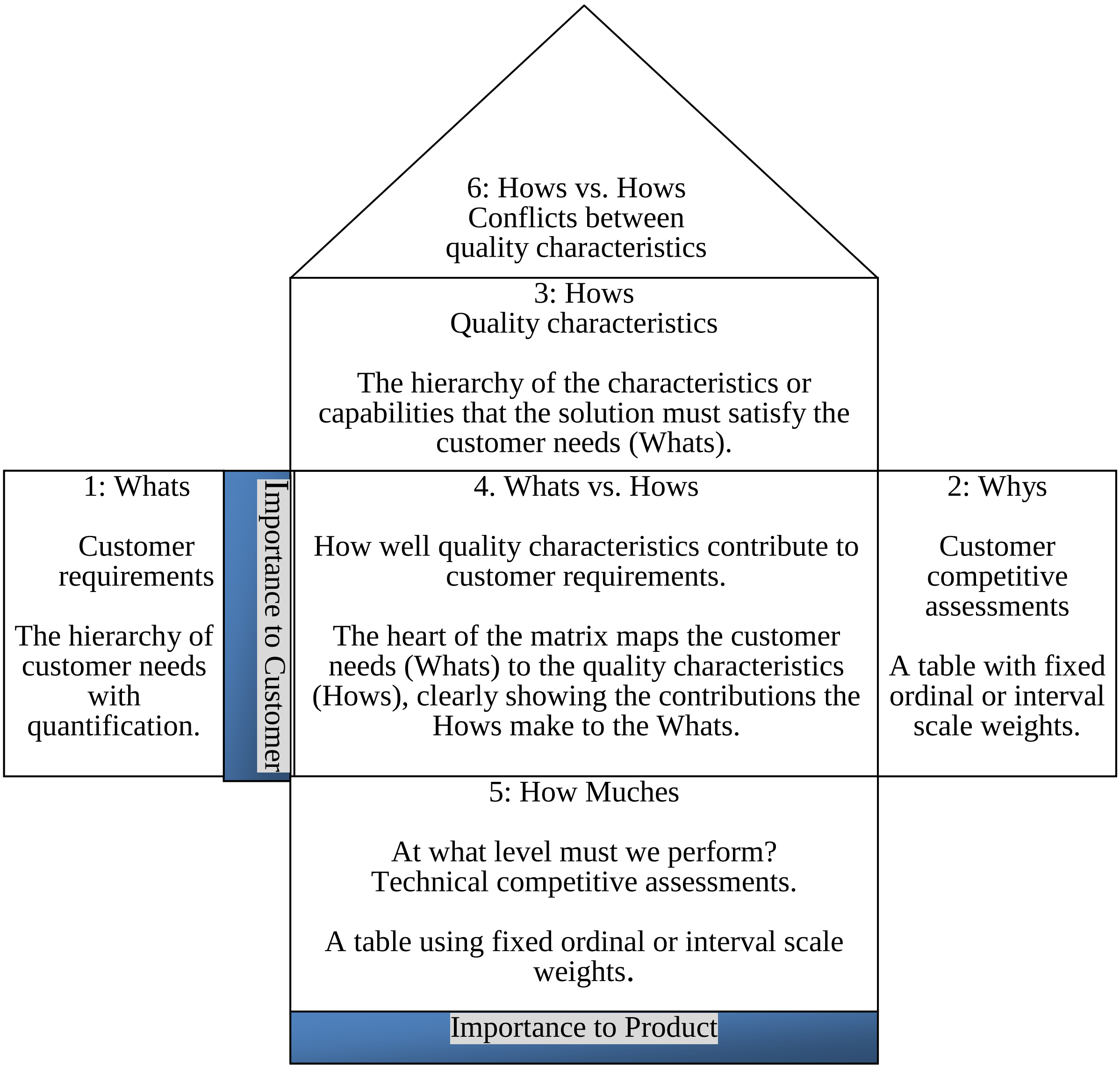
The basic structure of HOQ is a table with “Whats” as the labels on the left and “Hows” across the top. The roof is a diagonal matrix of "Hows vs. Hows" and the body of the house is a matrix of “Whats vs. Hows”. Both of these matrices are filled with indicators of whether the interaction of the specific item is a strong positive, a strong negative, or somewhere in between. Additional annexes on the right side and bottom hold the “Whys” and the “How Muches” (Akao, 1990). Rankings based on the Whys and the correlations can be used to calculate priorities for the Hows. QFD is an enabling tool for performance measurement to enable organizations measure their ability to meet customer requirements through basic prioritization and listing of customer wants, i.e. the ability to capture the voice of the customer (Mohamed, 1994). Mohamed also proposes that despite QFD with some benefits, however, it has some problems with the use of it. Some major problems are given as follows:

1. The complex nature of QFD.
2. The lack of planning and prioritizing.
3. Insufficient time.
4. A realistic management expectation.
5. Reluctance to involve customers too closely.
6. Resistance to change.
7. Not involving influences such as dealers, suppliers and other parties.
8. Lack of integration with other tools and techniques.
9. A difficulty in term-building.

The voice of the customer may be translated into the voice of the engineer through the process of QFD (Jack *et al.*, 1998). The three main goals in implementing QFD are:

1. Prioritize spoken and unspoken customer wants and needs.
2. Translate these needs into technical characteristics and specifications.
3. Build and deliver a quality product or service by focusing everybody toward customer satisfaction.

Overall, comprehensive QFD may involve four phases: Product Planning, Product Design, Process Planning and Process Control. Product Planning is to build the HOQ led by the marketing department (Joseph and Louis, 2009). It documents customer requirements, product measurements, competing product measures, and the technical ability of the organization to meet each customer requirement. The first phase in the implementation of the QFD process involves putting together a such as the one shown in Figure 2.2, which is for the development of a HOQ climbing harness (Hauser and Clausing, 1988). HOQ matrix is an analysis matrix intended to be the bridge between the world of the customer and the world of the developer. It is here that the "voice of the customer," or customer needs, are translated into the corresponding quality characteristics and capabilities that the solution will require. The HOQ matrix has several components/rooms and it is created before any design activities are performed. Figure 2.2 shows the six components/rooms of the traditional HOQ matrix and their explicit meanings.



Source: Step-by-Step QFD: Customer-Driven Product Design, 1998; Advanced QFD Applications, 2003.

Figure 2.2 Components/rooms of the HOQ matrix

Sullivan (1986) said that the main objective of any manufacturing company is to bring new (and carryover) products to market sooner than the competition with lower cost and improved quality. The mechanism to do this is called QFD. Reed and Jacobs (1993) provided some guidelines for implementing QFD. Hung *et al.* (2012) defined the basic background of the QFD method as twelve phases. To accomplish the process of HOQ in Figure 2.2, there are twelve steps to be proceeded step-by-step as follows:

Step 1: Customer Requirements – “Voice of the Customer”

The first step in a QFD project is to determine what market segments will be analyzed during the process and to identify who the customers are.

Step 2: Regulatory Requirements

The team must document requirements that are dictated by management or regulatory standards that the product must adhere to for the customer.

Step 3: Customer Importance Ratings

Customers then rate the importance of each requirement in the relationship matrix.

Step 4: Customer Rating of the Competition

In this step of the QFD process, there is remodeling that can take place in this part of the HOQ. Additional rooms that identify sales opportunities, goals for continuous improvement, customer complaints, etc., can be added.

Step 5: Technical Descriptors – "Voice of the Engineer"

The technical descriptors are attributes about the product or service that can be measured and benchmarked against the competition. Technical descriptors may use to determine product specification, however new measurements can be created to ensure that your product is meeting customer needs.

Step 6: Direction of Improvement

A determination must be made as to the direction of movement for each descriptor based on the technical descriptors.

Step 7: Relationship Matrix

The relationship matrix is where the determinations of the relationship between customers' needs and the company's ability to meet those needs.

Step 8: Organizational Difficulty

To rate the design attributes in terms of organizational difficulty, because it is possible that some attributes are in direct conflict.

Step 9: Technical Analysis of Competitor Products

To conduct a comparison of competitor technical descriptors to better understand the competition, engineering, then.

Step 10: Target Values for Technical Descriptors

To establish target values for each technical descriptor and they can then act as a base-line to compare against.

Step 11: Correlation Matrix

This room is designed for examining how each of the technical descriptors impacts each other and it makes the HOQ matrix look like a house with a roof. The team should document strong negative relationships between technical descriptors and work to eliminate physical contradictions.

Step 12: Absolute Importance

Finally, the numerical calculation of the absolute importance for each technical descriptor is the product of the cell value and the customer importance rating. Numbers are then added up in their respective columns to determine the importance for each technical descriptor.

2.5.3 Summary

The above process is then repeated in a slightly simplified way for the next three project phases. The main difference is that the translation objective is changed in different phases. QFD is a systematic means of ensuring that customer requirements are accurately translated into relevant technical descriptors throughout each stage of product development. Therefore, meeting or exceeding customer demands means more than just maintaining or improving product performance. It means designing and manufacturing products that delight customers and fulfill their unarticulated desires (Dean, 1992). Traditional quality-improvement and problem-solving methods use data (measures from an existing product or process) to find the root cause of defects or problems and remove them or solve them. In contrast, QFD's aim is to understand the customer's needs and use that understanding to drive design and development to ensure customer satisfaction on the first pass through development (Akao and Fujimoto, 2000).

From the above, the idea behind QFD is to transform the customer need into engineering technique through the importance implied in the correlationship matrix operation. Those importances also imply the degrees of customer satisfaction. In this research, we consider the risk reduction as the need of airport operator and the improvement measures is considered to be the engineering technique. This study then applies the QFD concept of translating customer needs (decreasing unacceptable risks) into engineering characteristics (analysis and prioritization of improvement measures) through taking some steps mentioned above (i.e. steps 1,3,5,7 and 12), providing the airport operator with a systematically improvement decision making suggestion.

2.6 Summary

Section 2.1 describes some literatures of the risk management and aviation risk management, and concludes that five steps of risk management can be carried out to ensure the aviation safety. By section 2.2, we can acquire professional information through the in-depth interviews to proceed with the airport airside risk analysis. Section 2.3 shows that most of the literatures explored aviation safety from the perspective of software-hardware facilities and human-machine interfaces while few studies explored the airport airside risk systematically. By section 2.4, we can find that few studies quantified the airport risks under the condition of only few aviation accident cases. This research tries to apply the possibility concept of fuzzy theory and fuzzy logic control method to assess the airport airside risks. And we apply the framework of FMECA to assess airport airside risks by decision factors of possibility, severity and severity. By section 2.5, QFD process may translate the voice of customer into the voice of the engineer. This research may apply the QFD concept to translate customer needs (decreasing unacceptable risks) into engineering characteristics (analysis and prioritization of improvement measures).

The purpose of this research aims at improving the shortcomings of traditional RPN and the difficulty of identification of threshold value through incorporating the FMECA concept and fuzzy logic method with weightings of risk decision factors to measure the Risk Priority Numbers (RPN). Compared with traditional methods of risk quantification or FMECA, this research may has the following advantages：1) fuzzy inference provides more realistic and flexible way to reflect the real situation of the ambiguous airport airside risk with imprecise information; 2) weights of risk decision factors can be employed to set improvement strategies in the future; 3) ambiguous risks can be ranked and represented in terms of precise RPN effectively; 4) by determining the threshold value of the risk assessment matrix more precisely, airport operator can explore unacceptable risk efficiently ; 5) by designing FMECA table systematically and assessing RPN, we can explore the hot spot of airport airside risk occurrence efficiently. The strategies to manage unacceptable risks assessed above typically include transferring the risk to another party, avoiding the risk, reducing the negative effect or possibility of the risk, or even accepting some or all of the potential or actual consequences of a particular risk, and the opposites for opportunities. After ranking those proposed improvement measures, the airport operator can make the improvement decision more efficiently. To illustrate the applicability, this research uses Taiwan Taoyuan International Airport (TTIA) as a case study.

CHAPTER 3. MODEL FRAMEWORK and METHODS of RISK ASSESSMENT

To identify, measure and assess the risk items and also analyze the improvement measures, this study employs the methods of literature review, in-depth interview, FMECA: RPN, fuzzy logic control, risk assessment matrix, and quality function deployment, which are discussed in this section.

3.1 Model Framework

This study proposes a systematic framework of risk management to analyze the airport airside risks from the airport operator's viewpoint through the FLC-based FMECA and QFD concept. The rational of this proposed model framework basically follows the stages of risk management: risk identification, risk measurement, risk assessment, and risk control. The risk management stages, applied methods, and their corresponding outputs of the proposed approach in this research are illustrated in Figure 3.1. Following are the description, rationale, and implementation steps of this research approach.

The first stage A is the risk identification; this research applies literature review method to extract the airport airside-related flight procedures, risk occurrence area, and risk item from the ICAO aviation accidents data base (ICAO, 2011). This research then identifies the specific airport airside risk scenario through the method of in-depth interview which was used by Irwin and Johnson (2005) to find deep understanding and information. The implementation step is described in step 1 in the following discussions.

Stage B is the risk measurement; this research applies the RPN method used in FMECA which is widely used as a quantitative tool to analyze the safety and reliability in many industries (Chang and Cheng, 2010). Wang *et al.* (2009) proposed fuzzy RPN to prioritize the failure modes. This research then uses the method of fuzzy logic control to evaluate the RPN value and risk level of each airport airside risk item. The implementation steps are described from step 2 to step 5 in the following discussions.

Stage C is the risk assessment; this research uses the LINEST function of EXCEL software to fit the weights of decision factors i.e. possibility, severity, and detectability. This research finds the threshold value and unacceptable risks through the risk assessment matrix. The implementation steps are described from step 6 to step 7 in the following discussions.

The last stage D is the risk control; this research applies the method of in-depth interview above-mentioned to develop some concrete improvement measures according to the specific airport risks. The implication behind QFD is to transform the customer need into engineering technique by the correlation matrix operation. This research applies the QFD procedure to analyze and prioritize the proposed improvement measures. The implementation steps are described from step 8 to step 9 in the following discussions.

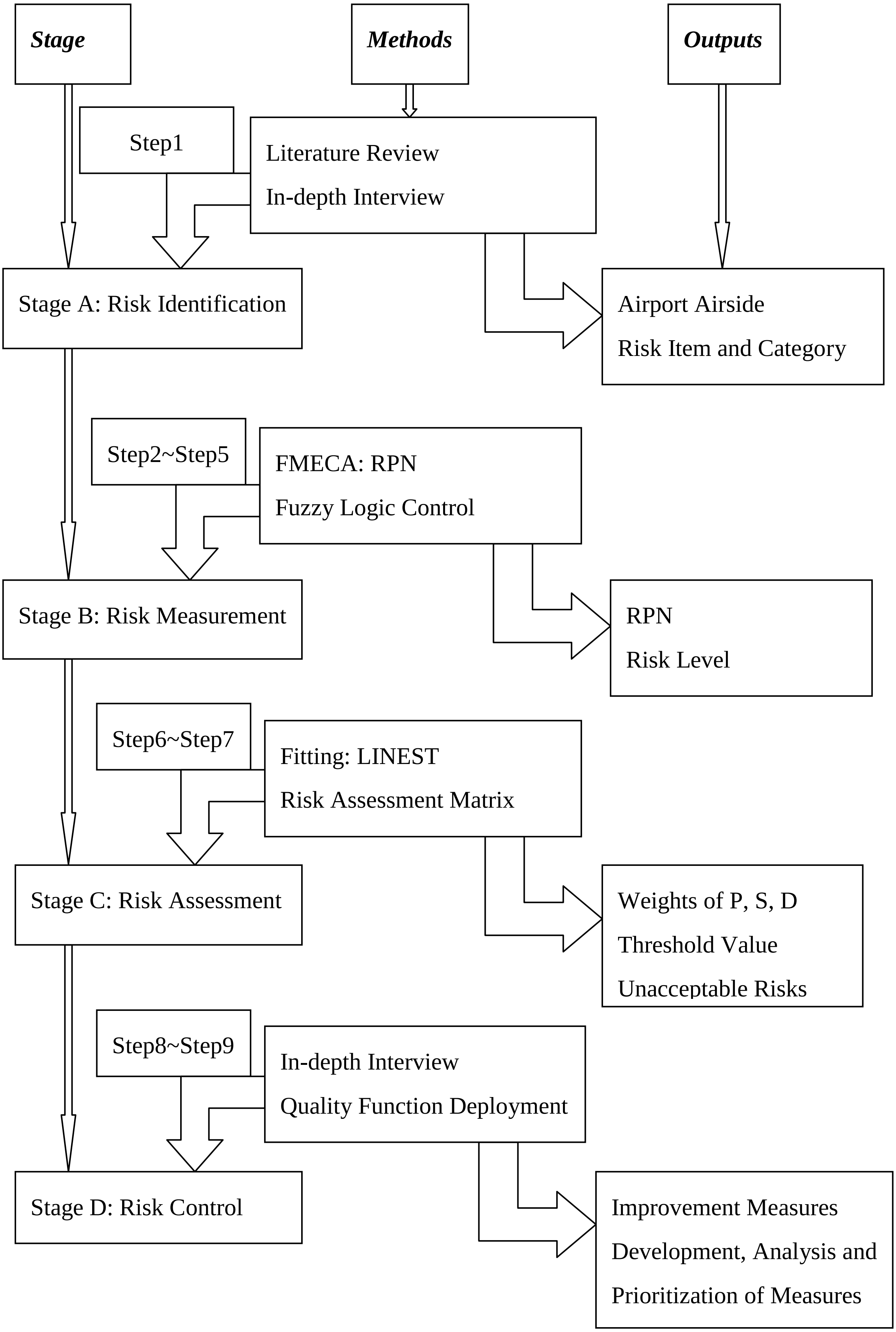
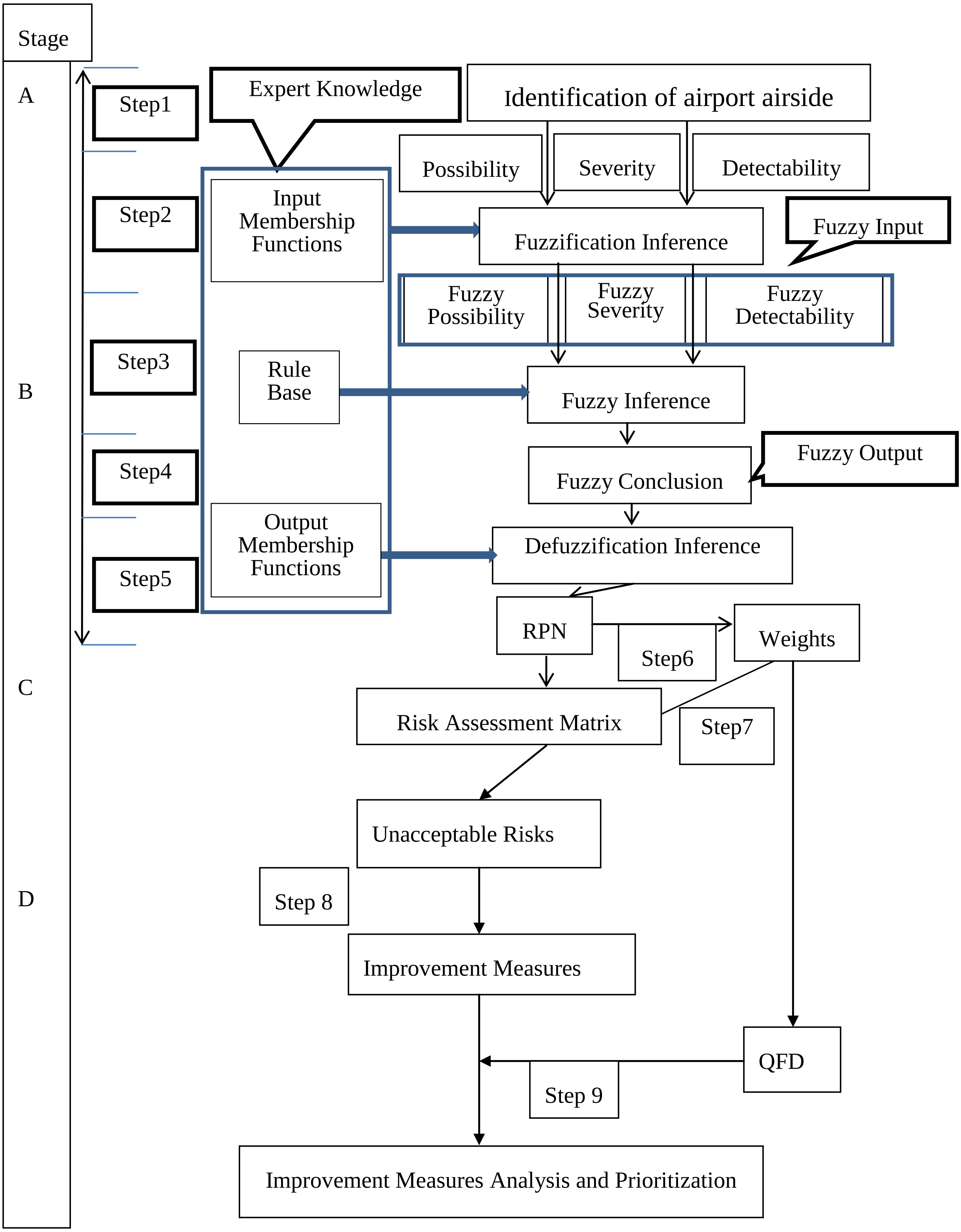


Figure 3.1 Model Framework of Risk Management

The more detail procedure of research steps in the above-mentioned risk management stages can be seen in Figure 3.2. And the detail description of steps will be discussed in the following sections. Among these nine steps, risk identification, measurement, and assessment from step 1 to step 7 are discussed in this chapter while the analysis of improvements from step 8 to step 9 is discussed in chapter 5.



A: Risk Identification B: Risk Measurement C: Risk Assessment
D: Improvement Measures Analysis and Priority

Figure 3.2 The Procedure of Risk Management Steps

3.2 Failure Modes, Effect and Criticality Analysis

In the RPN method the parameters used to determine the criticality of an item failure mode are its frequency of occurrence, the severity of its failure effects, and the likelihood that subsequent testing of the design will detect that the potential failure mode actually occurs (Bowles and Enrique, 1995). Traditionally, RPN is the product of probability, severity and detectability (Ford Motor Company, 1988). Sankar and Prabhu (2001) used the RPN ranks 1-1000 to represent the increasing risk of the 1000 possible severity-occurrence-detection combinations and interpreted them as if-then rules by an expert. But different sets of severity-occurrence-detection may produce the same RPN value, and their hidden risk implications may be different. Ahmet and Mehmet (2012) used the fuzzy technique for order preference by similarity to ideal solution (TOPSIS) based fuzzy analytical hierarchy process (FAHP) to find the most important and risky potential failure mode (PFM).

Daya and Raouf (1996) consider the importance of risk factors by using exponential weight. Lee and Chang (2005) proposed that the weight of decision factors (i.e. probability, severity and detectability) can indicate the importance implication of those decision factors. They also tried to apply the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method to allocate those weights of risk decision factors, but they still failed to determine the threshold of risk assessment matrix effectively. This research refers to the literatures of traditional RPN definition denoted possibility, severity and detectability as decision factors. We also include the weight of decision factor in the RPN computation and hope to find their respective importance. In order to resolve the problems mentioned above, this study formulates the RPN with criticality of risk decision factors in the form of exponential weight by

$$RPN_{ijk} = C \times P_{ijk}^{Wp} \times S_{ijk}^{Ws} \times D_{ijk}^{Wd} \qquad (1)$$

Where P: possibility, S: severity, D: detectability, C: constant, i: flight procedure, j: risk occurrence area, k: failure mode, W_p, W_s, W_d are the weights of possibility, severity and detectability, respectively.

Eq. (1) shows that the higher the possibility, severity, detectability of a risk item, the more critical the RPN is. Original values of possibility, severity, detectability and RPN were obtained from the expert in-depth interviews. Risks with a high RPN are assumed to be more important and should be given a higher priority than those having a lower RPN. Hence, this study considers possibility, severity, and detectability as state variables and RPN as a control variable in the following FLC process.

This study employs the LINEST function in the software of EXCEL to calibrate the weight of decision factors i.e. possibility, severity and detectability. The EXCEL LINEST function returns statistical information on the line of best fit, through a supplied set of the values of control and state variables. The control variable is RPN, the state variables are possibility, severity, and detectability.

The first step of fitting procedure is inputting all the state variables and control variable into Eq. (1) and then taking the form of natural logarithm on both sides of Eq. (1). The array of statistics returned from the EXCEL LINEST function can be used to analyze the validity of

Eq. (1) and its fitting results. The output includes coefficients, standard errors, t values of state variables and R^2.

A good FMEA can help analysts identify known and potential failure modes as well as their causes and effects, prioritize the identified failure modes and can also work out corrective actions for the failure modes (Liu *et al.*, 2011). To analyze the complicated airport airside risks, this study assesses the value of Possibility-Severity-Detectability in each failure mode and its corresponding RPN value, and rank them in terms of RPN value.

Considering that the estimation of RPN is a predicted value, there are no existing data of actual risk value to verify its accuracy. This research would not take the model validation and comparison studies.

3.3 Fuzzy Logic and Risk Assessment Matrix

Fuzzy logic provides a tool for directly working with the linguistic terms used in making the criticality assessment. A criticality assessment based on fuzzy logic allows an analyst to evaluate the risk associated with failure modes in a natural way (Bowles and Enrique, 1995). Fuzzy logic, based on the IF-THEN rules with expert's knowledge, formulates rules in linguistic terms rather than in numerical terms, which can deal with the situation such as the assessment of airport airside risk with insufficient and imprecise information. This study adopts fuzzy logic to analyze the airport airside risks and its process is discussed as follows and shown in Figure 3.2.

Step 1: Identification of the airport airside risks

According to ICAO aviation accidents data base described in chapter 2 (see Table 2.1); the airport airside risk items are defined and classed as follows:

1. Flight procedures:

The flight procedure refers to a period within a flight, and most of the procedures have sub procedures. Table 3.3 summarizes the procedures, definitions and sub procedures based on the ICAO aviation accidents data base.

Table 3.1 Flight Procedure Classification

Procedure	Definition	Sub procedure
STANDING (STD)	Prior to pushback or taxi, or after arrival, at the gate, ramp or parking area, while the aircraft is stationary.	● Engine(s) Not Operating. ● Engine(s) Start-up. ● Engine(s) Operating. ● Engine(s) Shut Down.
PUSHBACK/ TOWING (PBT)	Aircraft is moving in the gate, ramp, or parking area, assisted by a tow vehicle (tug).	● Assisted, Engine(s) Not Operating. ● Assisted, Engine(s) Start-up. ● Assisted, Engine(s) Operating. ● Assisted, Engine(s) Shut Down.
TAXI (TXI)	The aircraft is moving on the aerodrome surface under its own power prior to takeoff or after landing.	● Power Back: Takes place when the aircraft, under its own power, reverses from the stand or parking position. ● Taxi to Runway: Commences when the aircraft begins to move under its own power leaving the gate, ramp, apron, or parking area, and terminates upon reaching the runway. ● Taxi to Takeoff Position: From entering the runway until reaching the takeoff position. ● Taxi from Runway: Begins upon exiting the landing runway and terminates upon arrival at the gate, ramp, apron, or parking area, when the aircraft ceases to move under its own power.
TAKEOFF (TOF)	From the application of takeoff power, through rotation and to an altitude of 35 feet above runway elevation.	● Takeoff. From the application of takeoff power, through rotation and to an altitude of 35 feet above runway elevation or until gear-up selection, whichever comes first. ● Rejected Takeoff. During takeoff, from the point where the decision to abort has been taken until the aircraft begins to taxi from the runway.
INITIAL CLIMB (ICL)	From the end of the Takeoff sub phase to the first prescribed power reduction, or until reaching 1,000 feet above runway elevation or the VFR pattern, whichever comes first.	● None

EN ROUTE (ENR)	Instrument Flight Rules (IFR): From completion of Initial Climb through cruise altitude and completion of controlled descent to the Initial Approach Fix (IAF).	● Climb to Cruise: IFR: From completion of Initial Climb to arrival at initial assigned cruise altitude. VFR: From completion of Initial Climb to initial cruise altitude. ● Cruise: Any level flight segment after arrival at initial cruise altitude until the start of descent to the destination. ● Change of Cruise Level: Any climb or descent during cruise after the initial climb to cruise, but before descent to the destination. ● Descent IFR: Descent from cruise to either Initial Approach Fix (IAF) or VFR pattern entry.
Visual Flight Rules (VFR)	From completion of Initial Climb through cruise and controlled descent to the VFR pattern altitude or 1,000 feet above runway elevation, whichever comes first.	● VFR: Descent from cruise to the VFR pattern entry or 1,000 feet above the runway elevation, whichever comes first. ● Holding: Execution of a predetermined maneuver (usually an oval racetrack pattern) which keeps the aircraft within a specified airspace while awaiting further clearance. Descent during holding is also covered in this sub phase.
MANEUVERING (MNV)	Low altitude/aerobatic flight operations.	● Aerobatics: Any intentional maneuvering that exceeds 30 degrees of pitch attitude or 60 degrees of bank, or both, or abnormal acceleration (usually associated with air shows and military flight, or with related training flights). ● Low Flying: Intentional low-altitude flight not connected with a landing or takeoff, usually in preparation for or during observation work, demonstration, photography work, aerial application, training, sightseeing, ostentatious display, or other similar activity. For rotorcraft, this also includes hovering (not associated with landing or takeoff) and handling external loads.
APPROACH (APR)	Instrument Flight Rules (IFR): From the	● Initial Approach (IFR): From the IAF to the Final Approach Fix

	Initial Approach Fix (IAF) to the beginning of the landing flare. Visual Flight Rules (VFR): From the point of VFR pattern entry, or 1,000 feet above the runway elevation, to the beginning of the landing flare.	(FAF). ● Final Approach (IFR): From the FAF to the beginning of the landing flare. ● Circuit Pattern—Downwind (VFR): A flight path (normally 1,000 feet above the runway), which commences abeam the departure end of the runway and runs parallel to the runway in the direction opposite to landing, and terminates upon initiating the turn to base leg. ● Circuit Pattern—Base (VFR): From the start of the turn at end of downwind leg until the start of the turn for final. ● Circuit Pattern—Final (VFR): From the start of the turn to intercept the extended runway centerline, normally at the end of base leg, to the beginning of the landing flare. Includes VFR straight-in approaches. ● Circuit Pattern—Crosswind (VFR): A flight path of the VFR traffic pattern, which is perpendicular to the landing runway, crosses the departure end of the runway, and connects with the downwind leg. ● Missed Approach/Go-Around: From the first application of power after the crew elects to execute a missed approach or go-around until the aircraft re-enters the sequence for a VFR pattern (go-around) or until the aircraft reaches the IAF for another approach (IFR).
LANDING (LDG)	From the beginning of the landing flare until aircraft exits the landing runway, comes to a stop on the runway, or when power is applied for takeoff in the case of a touch-and-go landing.	● Flare: Transition from nose-low to nose-up attitude just before landing until touchdown. ● Landing Roll: After touchdown until aircraft exits the landing runway or comes to a stop, whichever occurs first. ● Aborted Landing after Touchdown: When an attempt is made to get airborne after touchdown (successful or not). This does not include the takeoff portion of a

		touch-and-go.
EMERGENCY DESCENT (EMG)	A controlled descent during any airborne phase in response to a perceived emergency situation.	● None
UNCONTROLLED DESCENT (UND)	A descent during any airborne phase in which the aircraft does not sustain controlled flight.	● None
POST-IMPACT (PIM)	Any of those portions of the flight which occurs after impact with a person, object, obstacle or terrain.	● None
UNKNOWN (UNK)	Phase of flight is not discernible from the information available.	● None

2. Risk occurrence areas:

According to the Figure 1.4 basic airport operations, we can conclude that airport airside risks may happened in areas between runway, taxiway, apron-gate, holding pad and terminal airspace.

3. Risk items:

The CAST/ICAO Common Taxonomy Team (CICTT) conclude the aviation occurrence categories as Abnormal Runway Contact, Controlled Flight Into or Toward Terrain, Fire/Smoke (Non-Impact), Fuel Related, Loss of Control – In flight, Midair/Near Midair Collision, Other, Ground Handling, Runway Excursion (Takeoff or Landing), System/Component Failure or Malfunction (Non-Powerplant), System/Component Failure or Malfunction (Powerplant), Unknown or Undetermined, Undershoot/Overshoot, Windshear or Thunderstorm, Aerodrome, Abrupt Maneuver, Air Traffic Management/Communications, Navigation, Surveillance, Bird, Cabin Safety Events, Evacuation, Fire/Smoke (Post-Impact), Ground Collision, Icing, Low Altitude Operations, Loss of Control – Ground, Runway Incursion – Animal, Runway Incursion – Vehicle, Aircraft or Person, Security Related and Turbulence Encounter. Those risks and their corresponding definition are shown in Table 2.1.

Owing to the individual condition are much different from diverse airports. Every single airport encountered with its own risk items. Some risks may be common but others may be very dissimilar. In the next section, this study will use TTIA as a case study to analyze its airside risks.

Step 2: Fuzzification of P, S, D and Risk

The Fuzzification process first converts the possibility, severity and detectability inputs into their linguistic variables, and then fuzzifies them to determine their degrees of membership through membership functions (MFs). A fuzzy set is completely characterized by its membership function (MF) which is a generalization of the indicator function in classical sets.

In fuzzy logic, it represents the degree of truth as an extension of valuation. Jin and Bimal (2002) synthesized that the general classification of MFs are Triangular MF, Trapezoidal (narrow/wide "shoulder") MF, Gaussian MF, Two-sided Gaussian MF, Bell-shaped (narrow/wide "shoulder") MF, Sigmoid-right MF, Sigmoid-left MF, Difference-sigmoid MF, Product-sigmoid MF, Polynominal-Z MF, Polynominal-S MF and Polynominal-PI (narrow/wide "shoulder") MF. Aditi *et al.* (2014) provided an interval-based theoretical explanation to prove that in principle, membership functions can be of different shape, but in practice, trapezoidal and triangular membership functions are most frequently used. Homaifar and McCormick (1995) examined the applicability of genetic algorithms (GA's) in the simultaneous design of membership functions and rule sets for fuzzy logic controllers, and proposed that fuzzy sets are most often triangular in shape. To sum up, the membership function of fuzzy numbers presented here is the most popular triangular one because it is easy to use and interpret. A triangular membership function of fuzzy number x in fuzzy set A can be defined as Eq. (2).

$$\mu_A(x) = A(x; x_m, x_s, x_M) = \begin{cases} 0, & x \le x_m \\ \left(\dfrac{x - x_m}{x_s - x_m}\right), & x_m \le x \le x_s \\ 1 - \left(\dfrac{x - x_s}{x_M - x_s}\right), & x_s \le x \le x_M \\ 0, & x \ge x_M \end{cases} \tag{2}$$

$$where \quad x_s = (x_m + x_M)/2$$

X_m, X_s and X_M denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event, respectively. A sample of a triangular fuzzy is shown in Figure 3.3.

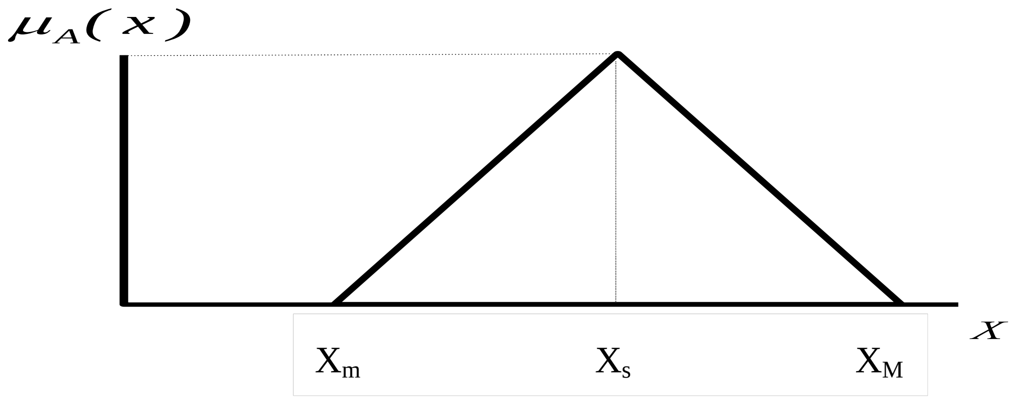


Figure 3.3 A Triangular Membership Function of X

Three classes of the linguistic variable, High, Moderate and Low, as defined in this study, are overlaps between adjacent membership functions and are shown in Figure 3.4.

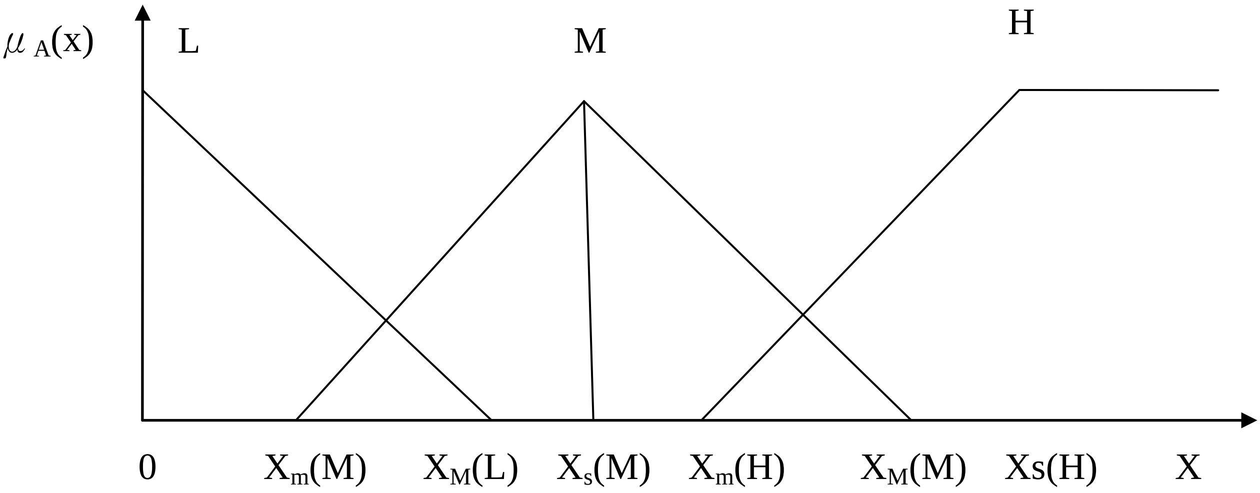


Figure 3.4 Three Classes of the Linguistic Variable

Step 3: Derivation of Fuzzy Rules between P, S, D and Risk

Fuzzy logic is a rule-based system written in the form of horn clauses (i.e., If-Then rules). Fuzzy inference rules are stored in the knowledge base of the system and have the general form: “If x is A and y is B Then z is C”, where A, B and C are the linguistic values defined by fuzzy sets in the universe of discourse X, Y and Z, respectively (Mohammad *et al.*, 2011). The If-Then rules have two parts: an antecedent (state variable), which is compared to the inputs, and a consequent (control variable), which is the result. All the rules that have any truth in their premises will fire and contribute to the fuzzy conclusion set.

Fuzzy rules may have two goals which are making a model of a process (physical, chemical, weather forecast, climate, human society etc.) with a declarative goal and making a control strategy having a process model already in mind. Both of these rule-based approaches can be derived from the direct expert knowledge or the indirect observation data. Sushmita and Yoichi (2000) developed an exhaustive survey of neuro-fuzzy rule generation algorithms from artificial neural networks. Models are generated form fuzzy knowledge-based networks, which initially encode some crude domain knowledge, are found to result in more refined rules and grouped on the basis of their level of neuro-fuzzy synthesis.

Fuzzy rules are generated through expert knowledge and applied the Mamdani-type fuzzy inference system (FIS) in this study. These rules can be viewed as relations of between state variables and a control variable, or a qualitative evaluation of riskiness for various combinations of possibility, severity, and detectability. The knowledge is represented as:

“R^i: IF x_1 is A_1^i and x_2 is A_2^i …and x_n is A_n^i, THEN y^i is B^i”

Where $R^i(i=1,2,\ldots,k)$ denotes the i^{th} fuzzy rule, $x_j(j=1,2,\ldots,n)$ is the input, y^i is the output of the fuzzy rule R^i, and $A_1^i,A_2^i,\ldots,A_k^i$, $B^i(i=1,2,\ldots,k)$ are fuzzy membership functions usually associated with linguistic terms. In this research, x_n represents possibility, severity and detectability respectively, and y denotes risk. One example is “If possibility (P) is Low, severity (S) is Low and detectability (D) is High, then risk (R) is Low”. For the fuzzy criticality analysis, we express the failure possibility through its occurrence, the seriousness of a failure through its severity, and how easy it is to detect a failure through its detectability. Each rule is fired to a degree that is a function of the membership to which its antecedent matches the input.

Step 4: Evaluation to a fuzzy conclusion

The fuzzy inference process uses 'min-max inference' to calculate the rule conclusions based on the system input values (Zadeh, 1992). The result of this process is called the "fuzzy conclusion". The truth-value of a rule is determined from the conjunction of the rule antecedents. With conjunction defined as 'minimum', rule evaluation then consists of determining the smallest (minimum) rule antecedent, which is taken to be the truth-value of the rule. This truth-value is then applied to all consequences of the rule. If any fuzzy output is a consequence of more than one rule, that output is set to the highest (maximum) truth-value of all the rules that include it as a consequence. The result of the rule evaluation is a set of fuzzy conclusions that reflect the effects of all the rules whose truth-values are greater than zero (Bowles and Enrique, 1995). The fuzzy conclusion process goes through the stages of Fuzzification of inputs and output, application of fuzzy operation and implication as well as aggregation method (Xu *et al.*, 2002). The fuzzy conclusion is calculated by the intersection rule of fuzzy sets which is very convenient method for representing some form of uncertainty. In this research, the membership function of risk (y^i) is defined as:

"$\mu^i(y^i)=\mu^i(A_1 \cap A_2 \cap \ldots \cap A_n) = \mathrm{Min}(\mu^i(x^i_1),\ \mu^i(x^i_2),\ldots,\mu^i(x^i_n))$"

Where A_n denotes the n^{th} input condition (i.e. possibility, severity and detectability), $\mu^i(y^i)$ denotes the membership function of risk.

Step 5: Defuzzification to a crisp RPN

The input to the fuzzy system is a scalar value that is fuzzified. The fuzzy output of each rule is needed to be converted into a scalar output quantity so that the nature of the action to be performed can be determined by the system. The result of fuzzy operations is a fuzzy number and in some situations a single scalar quantity is needed as an output. To establish how risky the airport is and prioritize its failure modes, it is required to convert a fuzzy number into a crisp value. The defuzzification process is required to decipher the meaning of the fuzzy conclusions and their membership values, and resolve conflicts between differing results, which may have been triggered during the rule evaluation (Bowles and Enrique, 1995). Before an output is defuzzified all the fuzzy outputs of the system are aggregated with a union operator which is the max of the set of given membership functions and can be expressed as "$\mu_A=\cup_i(\mu^i(x^i_1))$". In this research, the truth-value (degree of membership) of risk (y^i) is defined as:

"$\mu_B(y^i)=\ \cup_B(\mu(x^i_A))= \mathrm{Max}(\mu(x^i_1),\ \mu(x^i_2),\ldots,\mu(x^i_n))$"

Where A set denotes the input linguistic variable (i.e. possibility, severity and detectability), B set denotes the output linguistic variable of risk and $\mu_B(y^i)$ presents the truth-value of risk.

Defuzzification is the process of producing a quantifiable result in fuzzy logic, given fuzzy sets and corresponding membership degrees. Defuzzification of sub process means that the fuzzy result is converted in a crisp value. There are several available, theoretical and practical defuzzification methods for the fuzzy rule evaluation in the previous literatures. Leekwijck and Kerre (1999) summarized some different methods of defuzzification as following: AI (adaptive integration), BADD (basic defuzzification distributions), BOA (bisector of area), CDD (constraint decision defuzzification), COA (center of area), COG (center of gravity), ECOA (extended center of area), EQM (extended quality method), FCD (fuzzy clustering defuzzification), FM (fuzzy mean), FOM (first of maximum), GLSD (generalized level set defuzzification), ICOG (indexed center of gravity), IV (influence value), LOM (last of maximum), MeOM (mean of maxima), MOM (middle of maximum), QM (quality method), RCOM (random choice of maximum), SLIDE (semi-linear defuzzification) and WFM (weighted fuzzy mean). Weights mean of maximum (WMOM), centroid method (or center of area-COA) and α-cut methods are the most common defuzzification methods (Lee, 1990 and Sugeno, 1985). Wang *et al.* (2009) proposed fuzzy failure mode and effect analysis with weighted geometric mean for prioritization of failure modes by fuzzy risk priority numbers. Pokorádi (2009) used the WMOM to assess the building service mechanical and industrial day's risk. Tamás and László (2014) proposed a modified fuzzy rule based risk assessment method for the risk assessment of hydraulic systems by WMOM to summarize defuzzification which gives better crisp values for risk in risk assessment. To sum up, the WMOM method is widely used in different areas to be an effective defuzzification procedure. This study adopts the WMOM method whose formula is:

$$Z = \sum_{i=1}^{n} w_i x_i \Big/ \sum_{i=1}^{n} w_i \tag{3}$$

Where n = the number of quantified risk conclusions;

x_i = the support value at which the ith membership function reaches its maximum value;

w_i = the degree of truth of the ith membership function;

Z = the Weighted Mean of Maximum conclusion.

The Z value represents crisp ranking from the fuzzy conclusion set. In this study, it is defined as RPN.

Step 6: Generation of weights of P, S and D

The RPN method uses linguistic terms to rank the possibility, severity and the detectability on a numeric scale from 0 to 100. These rankings are then multiplied with exponential weight form to give the RPN (See Eq. (1)). According to all crisp inputs of Possibility, Severity, Detectability and crisp outputs of RPN, this study applies the Eq. (1) to compute the corresponding weights（W_p, W_s, W_d）and the constant C value. The control variable is RPN and the state variables are possibility, severity, and detectability. The first step of fitting procedure is inputting all the state variables and control variable into Eq. (1) and then taking the form of natural logarithm on both sides of Eq. (1). Finally, we can acquire the weight value of decision factors and the array of statistics by using "EXCEL" application software and its multiple linear regression function i.e. LINEST. The weight value represents the importance of risk decision factors. When there are planning strategies to reduce risk in the future, the strategies to lower severity of risk should be considered first to have a greater achievement if the weight of severity is the highest.

Step 7: Risk Assessment Matrix and the threshold value

Because the causes of airport airside risks are very complicated, mapping risk assessment matrix traditionally is rough and unable to define the existing risk threshold value objectively.

This study conducts questionnaire and responses from experts to construct fuzzy membership function, formulate linguistic class, evaluation criteria and establishes expert's rules. Furthermore, this study incorporates the weight of the decision factor through fuzzy logic method and then determines risk assessment matrix threshold value to assess the airport airside risk effectively.

Risk assessment is the process by which operators focus on critical areas of concern and prioritize their use of resources in order to maximize the improvement efforts. Katz and Robinson (1991) presented a risk-assessment matrix designed to improve permanency planning practice through early identification of foster children who have the least chance of returning to their families. In making strategic decisions, operators routinely try to predict the benefits and/or harm that might be caused by implementing or failing to implement those decisions. The Risk Assessment Matrix can be viewed as a logical extension of that process. It provides a systematic method for assigning a risk level to a failure mode based on the possibility, severity and detectability of the occurrence. However, because the ambiguous characteristic of inputs (possibility, severity, detectability) and outputs (risk) for uncertain consequences. Inputs to Risk Assessment Matrix and resulting outputs require subjective interpretation, and different users may obtain opposite ratings of the same quantitative risks. These limitations suggest that Risk Assessment Matrices should be used with caution, and only with careful explanations of embedded judgments. This study constructs the basic structure of a Risk Assessment Matrix shown in Table 3.4.

Table 3.2 Structure of Risk Assessment Matrix

	POSSIBILITY		
SEVERITY	L (Low)	M (Moderate)	H (High)
H (High)	**Reviewed risk**	***Unaccepted risk***	***Unaccepted risk***
M (Moderate)	Accepted risk	**Reviewed risk**	***Unaccepted risk***
L (Low)	Accepted risk	Accepted risk	**Reviewed risk**

Although airport operators can identify the risk categorization by possibility, severity and detectability through Risk Assessment Matrix, the sequential improvement of risk items with same risk categorization cannot be determined exactly without the exactly RPN value. To solve these problems, this study identifies the threshold value between reviewed risks and acceptable risks, and the threshold value between reviewed risks and unaccepted risks through the ranking of RPN value.

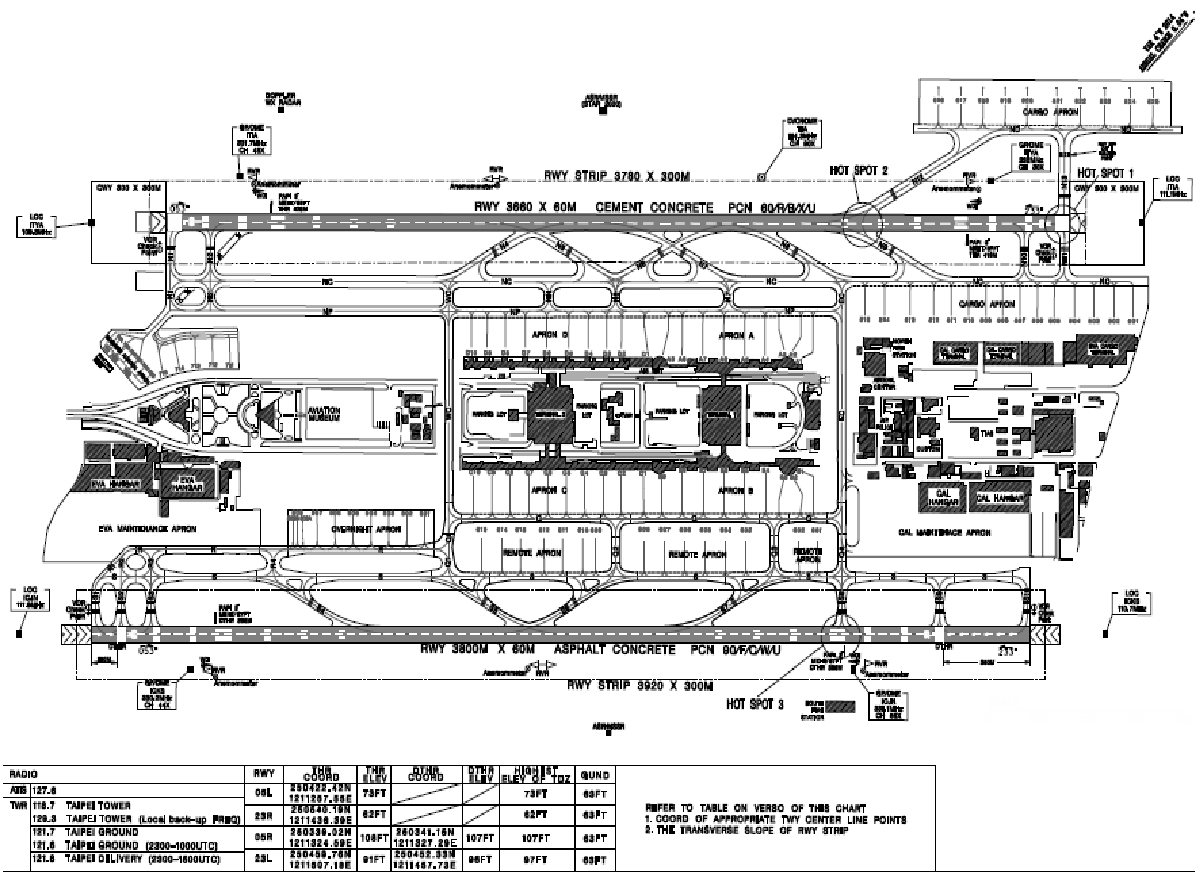
CHAPTER 4. CASE STUDY of RISK ASSESSMENT

4.1 Case Background and Procedures

Taiwan Taoyuan International Airport (TTIA) located in Taoyuan City (IATA: TPE, ICAO: RCTP), forty kilometers southwest of Taipei in northern Taiwan, is the largest and busiest international airport serving the capital city of Taiwan, Taipei, and the northern parts of the country. It is one of five Taiwanese airports with regular international flights, and is by far the busiest international air entry point amongst them. It is the main international hub for China Airlines and EVA Air as well. The airport opened for commercial operations in 1979 and is an important regional trans-shipment center, passenger hub, and gateway for destinations in China and the rest of Asia. ACI (Airports Council International) annual world airport traffic report indicated that TTIA was the 15th busiest airport worldwide in terms of international passengers' number and 10th busiest in terms of international freight traffic in 2013 and handled a total of 35,804,465 passengers and 2,088,726,700 kg of freight in 2014 (ACI, 2013). By the way, TTIA is surrounded with low-lying plains, interconnected mountains and plateaus. It has a humid subtropical climate, with mild to warm winters and hot summers, typical of northern Taiwan.

TTIA currently has two terminals which are connected by two, short people movers. Terminal 1 is the original passenger terminal of the TTIA and the design of the building is based on the main terminal of Washington Dulles International Airport. Terminal 1 featured 22 gates, a row of 11 gates are located on the north end of the airfield facing the north runway and another row of eleven gates are located on the south end airfield facing the south runway. Currently Terminal 1 has 18 gates and all gates are equipped with jet ways. Terminal 2 opened in 2000 to reduce congestion in the aging Terminal 1. Only the South Concourse had been completed by the time the terminal opened. The South Concourse alone has ten gates, each with two jet ways and their own security checkpoints. The North Concourse opened later in 2005, bringing the total number of gates for Terminal 2 to twenty gates; the security checkpoints were moved to a central location in front of the passport control. The 318,000 m^2 facility is capable of handling seventeen million passengers per year. The Southern and Northern Concourses are also known as Concourse C and Concourse D, respectively. Terminal 2 is also currently undergoing an expansion project that will increase the terminal's annual passenger capacity by five million people.

The runways and taxiways are set to be expanded by early 2015 to accommodate large planes (including the Airbus A380) at a cost of NT$10.7 billion. The runways will undergo their first major resurfacing and length extension in 30 years. Navigation facilities will also be upgraded to reduce the effects of bad weather on airport operations. A third terminal is being planned and is expected to handle forty-three million passengers per year when completed. The terminal will be located west of the existing Terminal 2, with facilities for entertainment, shopping, conferences and accommodations. Terminal 3 is scheduled to be completed in 2021 and the satellite terminals for check-in and additional buildings for auxiliary facilities are planned as well. TTIA is the main gateway into Taiwan and operated by Taoyuan International Airport Corporation Ltd. Which is a state-owned corporation formally established in November 2010 under the auspices of the Ministry of Transportation and Communications (MOTC). This study uses TTIA as a case study. Figure 4.1 shows the TTIA aerodrome chart.



Source: Taoyuan Airport Corporation, 2014.

Figure 4.1 TTIA Aerodrome Chart

In order to investigate the airport airside risks occurred at TTIA, this study conducts an in-depth survey by five experts (including one airline practitioner, one flyer and three government officials). They are all safety-related experts with years' experience. The questions include the possibility, severity, detectability and RPN using the linguistic term set ｛High, Moderate, Low｝, each expert specifies the value range for each term between 0 and 100, represented as a triangle fuzzy number. The details of in-depth interview process, questionnaires (see APPENDIX I), fundamental analyses and results are illustrated in the following sections. And the procedures of conducting the case study are as follows:

Step 1: Identification of the TTIA airside risks
Step 2: Fuzzification of P, S, D and risk
Step 3: Derivation of the fuzzy rule
Step 4: Evaluation to a fuzzy conclusion
Step 5: Defuzzification to a crisp RPN
Step 6: Generation of the weights of P, S and D
Step 7: Risk assessment matrix and threshold value

The detail step operation and results analysis of risk assessment in the case study are discussed in the following sections.

4.2 Risk Identification

Step 1: Identification of the TTIA airside risks

This study first extracts six airport airside-related flight operation procedures and their corresponding occurrence areas based on fourteen flight operation procedures and twenty-eight categories of accidents in ICAO aviation accidents data base (ICAO ADREP 2000 Taxonomy, 2010) by expert interview, and then identifies fourteen airport airside-related risk items shown in Table 4.1. Each risk item and its corresponding failure mode code and definition is shown in Table 4.2. Table 4.1 is derived by the experts based on TTIA characteristics, starting with finding area that might interact with the flight procedure, then we examine the twenty-eight categories of accidents in ICAO aviation accidents data base to figure out the risk item that might happen from the flight procedure or airport area.

Table 4.1 Airport Airside Risk Items. Acronyms are Defined in Table 4.2.

Flight procedure	Risk occurrence area	Failure mode (risk item)
STANDING (STD)	Apron-Gate Area	ADRM、F-NI、RAMP、SEC
	Holding Pad	ADRM、ATM、F-NI、RAMP、SEC
PUSHBACK /TOWING(PBT)	Apron-Gate Area	ADRM、ATM、F-NI、RAMP、ICE、LOC-G、SEC
TAXI (TXI)	Taxiway System	ADRM、ATM、F-NI、RAMP、GCOL、ICE、LOC-G、SEC
	Holding Pad	ADRM、ATM、F-NI、RAMP、ICE、LOC-G、SEC
	Runway	ARC、ADRM、ATM、F-NI、RAMP、GCOL、ICE、LOC-G、RE、RI-A、RI-VAP、SEC
TAKEOFF (TOF)	Terminal Airspace	ARC、ADRM、ATM、CFIT、F-NI、SEC
APPROACH (APR)	Terminal Airspace	ADRM、ATM、CFIT、F-NI、SEC
LANDING (LDG)	Taxiway System	ADRM、ATM、F-NI、RAMP、GCOL、ICE、LOC-G、SEC
	Runway	ARC、ADRM、ATM、CFIT、F-NI、RAMP、GCOL、ICE、LOC-G、RE、RI-A、RI-VAP、SEC、USOS

Table 4.2 Risk Item, Failure Mode (FM) Code and Definition

Risk Item	FM Code	Definition
ARC	FM1	Abnormal runway contact (Any landing or takeoff involving abnormal runway or landing surface contact.)
ADRM	FM2	Aerodrome (Aerodrome design, service, or functionality issues are evident.)
ATM	FM3	Air traffic management (ATM) or communications/navigation/ surveillance (CNS) service issues are evident.
CFIT	FM4	Controlled flight into or toward terrain (In-flight collision or near collision with terrain, water, or obstacle without indication of loss of control.)
F-NI	FM5	Fire/smoke (non-impact) (Fire or smoke in or on the aircraft, in flight or on the ground, which is not the result of impact.)
RAMP	FM6	Ground handling (Occurrences during or from ground handling operations.)
GCOL	FM7	Ground collision (Collision while taxiing to or from a runway.)
ICE	FM8	Icing (Accumulation of snow, ice, or frost on aircraft surfaces that adversely affects aircraft control or performance.)
LOC-G	FM9	Loss of control - ground (Loss of aircraft control while the aircraft is on the ground)
RE	FM10	Runway excursion (A veer off or overrun off the runway surface)
RI-A	FM11	Runway incursion - animal (Collision with, risk of collision, or evasive action taken by an aircraft to avoid an animal on a runway in use.)
RI-VAP	FM12	Runway incursion - vehicle, a/c or person (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.)
SEC	FM13	Security related (Criminal/Security acts, which result in accidents or incidents.)
USOS	FM14	Undershoot/overshoot (A touchdown off the runway surface.)

4.3 Risk Measurement

Step 2: Fuzzification of P, S, D and risk

After a cautioned in-depth survey, this study summarizes the possibility, severity, detectability, risk level linguistic level results shown in Table 4.3-Table 4.6; and listed the assessment value of possibility, severity and detectability in Table 4.7.

Table 4.3 Possibility Linguistic Level Result

Linguistic Variable / Expert	High	Moderate	Low
Expert A	(82,95)	(45,82)	(0,45)
Expert B	(74,90)	(35,74)	(0,35)
Expert C	(78,98)	(32,78)	(0,32)
Expert D	(80,100)	(46,80)	(0,46)
Expert E	(78,96)	(45,78)	(0,45)

Table 4.4 Severity Linguistic Level Result

Linguistic Variable / Expert	High	Moderate	Low
Expert A	(56,95)	(30,56)	(0,30)
Expert B	(72,98)	(33,72)	(0,33)
Expert C	(58,95)	(28,58)	(0,28)
Expert D	(74,100)	(35,74)	(0,35)
Expert E	(70,96)	(32,70)	(0,32)

Table 4.5 Detectability Linguistic Level Result

Linguistic Variable / Expert	High	Moderate	Low
Expert A	(70,100)	(42,70)	(0,42)
Expert B	(68,96)	(38,68)	(0,38)
Expert C	(66,95)	(33,66)	(0,33)
Expert D	(71,99)	(40,71)	(0,40)
Expert E	(67,98)	(39,67)	(0,39)

Table 4.6 Risk Level Linguistic Level Result

Linguistic Variable / Expert	High	Moderate	Low
Expert A	(64,95)	(22,64)	(0,22)
Expert B	(75,98)	(30,75)	(0,30)
Expert C	(82,96)	(32,82)	(0,32)
Expert D	(80,100)	(33,80)	(0,33)
Expert E	(78,100)	(28,78)	(0,28)

Table 4.7 Assement Value of Possibility, Severity and Detectability

Procedure	Risk Occurrence Area	FM#	Possibility	Severity	Detectability
STANDING	Apron-Gate Area	FM2	15	10	10
		FM5	18	46	5
		FM6	37	34	35
		FM13	8	30	82
	Holding Pad	FM2	14	45	8
		FM3	14	48	12
		FM5	12	52	6
		FM6	18	56	20
		FM13	6	30	62
PUSHBACK/	Apron-Gate Area	FM2	5	24	14
		FM3	16	50	24
TOWING		FM5	20	58	10
		FM6	22	62	14
		FM8	4	30	5
		FM9	18	48	10
		FM13	6	38	64
TAXI	Taxiway System	FM2	10	72	30
		FM3	12	90	29
		FM5	18	84	10
		FM6	22	88	28
		FM7	12	90	8
		FM8	2	80	10
		FM9	20	92	12
		FM13	5	30	28
	Holding Pad	FM2	8	52	42
		FM3	10	86	30
		FM5	10	80	10
		FM6	18	70	20
		FM8	6	30	17
		FM9	4	48	8
		FM13	2	30	32
	Runway	FM1	15	88	22

Procedure	Risk Occurrence Area	FM#	Possibility	Severity	Detectability
		FM2	14	82	30
		FM3	16	94	24
		FM5	22	92	10
		FM6	26	92	30
		FM7	14	94	10
		FM8	2	86	12
		FM9	22	98	12
		FM10	19	98	63
		FM11	42	88	79
		FM12	43	96	58
		FM13	4	66	62
TAKEOFF	Terminal Airspace	FM1	29	92	82
		FM2	4	87	18
		FM3	26	98	69
		FM4	19	92	16
		FM5	6	92	28
		FM13	4	78	30
APPROACH	Terminal Airspace	FM2	6	52	22
		FM3	18	98	73
		FM4	4	99	30
		FM5	6	76	30
		FM13	4	62	48
LANDING	Taxiway System	FM2	12	88	19
		FM3	18	94	30
		FM5	10	90	16
		FM6	16	88	7
		FM7	16	92	12
		FM8	2	86	8
		FM9	22	90	11
		FM13	2	30	19
	Runway	FM1	41	95	59
		FM2	16	90	30

Procedure	Risk Occurrence Area	FM#	Possibility	Severity	Detectability
		FM3	14	94	20
		FM4	8	98	23
		FM5	10	91	14
		FM6	16	90	22
		FM7	12	98	8
		FM8	2	88	10
		FM9	18	96	10
		FM10	16	97	15
		FM11	42	96	68
		FM12	41	98	57
		FM13	7	68	30
		FM14	16	97	20

Based on the expert questionnaire and Eq. (2) mentioned above, the scales and membership functions identified by triangular fuzzy number corresponding to each fuzzy linguistic variable are shown in Table 4.8-Table 4.11.

Table 4.8 Possibility Evaluation Criteria

Linguistic Variable	Definitions	Triangular Fuzzy Number
High	Repeated failures	（74,100,100）
Moderate	Occasional failures	（32,57,82）
Low	Relatively few failures	（0,0,46）

Table 4.9 Severity Evaluation Criteria

Linguistic Variable	Definitions	Triangular Fuzzy Number
High	Serious property loss or death	（56,100,100）
Moderate	Property loss or life injury	（28,51,74）
Low	Slight property loss	（0,0,35）

Table 4.10 Detectability Evaluation Criteria

Linguistic Variable	Definitions	Triangular Fuzzy Number
High	Failure is hardly detected	（66,100,100）
Moderate	Failure may be detected	（33,52,71）
Low	Failure is easily be detected	（0,0,42）

Table 4.11 Risk Level Evaluation Criteria

Linguistic Variable	Definitions	Triangular Fuzzy Number
High	Unacceptable risk	（64,100,100）
Moderate	Reviewed risk	（22,52,82）
Low	Acceptable risk	（0,0,33）

To fuzzify the inputs, this study puts the possibility, severity and detectability assessment on the corresponding scale and determines the degree of membership in the corresponding fuzzy sets. Take the evaluation of ground handling risk occurring at apron-gate in the standing procedure as an example: its possibility, severity and detectability are assessed as 37, 34 and 35 respectively. Referring to Eq. (2) and Table 4.8, a possibility of 37 means that it will have a low possibility with a membership of 0.196, and a moderate possibility with a membership of 0.2 (See Figure 4.2).

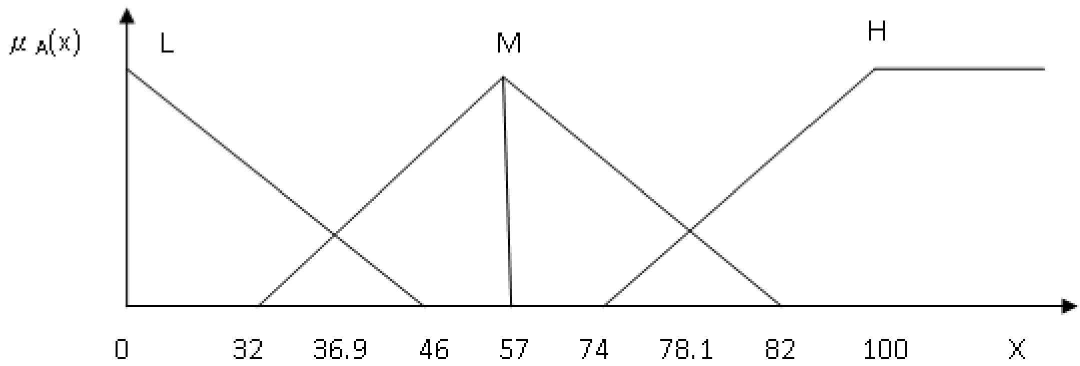


Figure 4.2 Membership Function of Possibility

Table 4.12 shows the degree of membership (d.m.) of possibility, severity and detectability calculated by Eq. (2). The corresponding linguistic variable (l.b.) was shown as well in Table 4.12.

Table 4.12 Degree of Membership (d.m.) and Linguistic Variable (l.b.)

Procedure	Risk Occurrence Area	FM#	P-d.m.	l.b.	S-d.m.	l.b.	D-d.m.	l.b.
STANDING	Apron-Gate Area	FM2	0.67	L	0.71	L	0.76	L
		FM5	0.61	L	0.78	M	0.88	L
		FM6	0.20	M	0.26	M	0.17	L
		FM13	0.83	L	0.14	L	0.47	H
	Holding Pad	FM2	0.70	L	0.74	M	0.81	L
		FM3	0.70	L	0.87	M	0.71	L
		FM5	0.74	L	0.96	M	0.86	L
		FM6	0.61	L	0.78	M	0.52	L
		FM13	0.87	L	0.14	L	0.53	M
PUSHBACK/	Apron-Gate Area	FM2	0.89	L	0.31	L	0.67	L
		FM3	0.65	L	0.96	M	0.43	L
TOWING		FM5	0.57	L	0.70	M	0.76	L
		FM6	0.52	L	0.52	M	0.67	L
		FM8	0.91	L	0.14	L	0.88	L
		FM9	0.61	L	0.87	M	0.76	L
		FM13	0.87	L	0.43	M	0.63	M
TAXI	Taxiway System	FM2	0.78	L	0.36	H	0.29	L
		FM3	0.74	L	0.77	H	0.31	L
		FM5	0.61	L	0.64	H	0.76	L
		FM6	0.52	L	0.73	H	0.33	L
		FM7	0.74	L	0.77	H	0.81	L
		FM8	0.96	L	0.55	H	0.76	L
		FM9	0.57	L	0.82	H	0.71	L
		FM13	0.89	L	0.14	L	0.33	L
	Holding Pad	FM2	0.83	L	0.96	M	0.47	M
		FM3	0.78	L	0.68	H	0.29	L
		FM5	0.78	L	0.55	H	0.76	L
		FM6	0.61	L	0.32	H	0.52	L
		FM8	0.87	L	0.14	L	0.60	L
		FM9	0.91	L	0.87	M	0.81	L
		FM13	0.96	L	0.14	L	0.24	L

Procedure	Risk Occurrence Area	FM#	P-d.m.	l.b.	S-d.m.	l.b.	D-d.m.	l.b.
	Runway	FM1	0.67	L	0.73	H	0.48	L
		FM2	0.70	L	0.59	H	0.29	L
		FM3	0.65	L	0.86	H	0.43	L
		FM5	0.52	L	0.82	H	0.76	L
		FM6	0.43	L	0.82	H	0.29	L
		FM7	0.70	L	0.86	H	0.76	L
		FM8	0.96	L	0.68	H	0.71	L
		FM9	0.52	L	0.95	H	0.71	L
		FM10	0.59	L	0.95	H	0.58	M
		FM11	0.40	M	0.73	H	0.38	H
		FM12	0.44	M	0.91	H	0.32	M
		FM13	0.91	L	0.35	M	0.53	M
TAKEOFF	Terminal Airspace	FM1	0.37	L	0.82	H	0.47	H
		FM2	0.91	L	0.70	H	0.57	L
		FM3	0.43	L	0.95	H	0.89	M
		FM4	0.59	L	0.82	H	0.62	L
		FM5	0.87	L	0.82	H	0.33	L
		FM13	0.91	L	0.50	H	0.29	L
APPROACH	Terminal Airspace	FM2	0.87	L	0.96	M	0.48	L
		FM3	0.61	L	0.95	H	0.21	H
		FM4	0.91	L	0.98	H	0.29	L
		FM5	0.87	L	0.45	H	0.29	L
		FM13	0.91	L	0.52	M	0.79	M
LANDING	Taxiway System	FM2	0.74	L	0.73	H	0.55	L
		FM3	0.61	L	0.86	H	0.29	L
		FM5	0.78	L	0.77	H	0.62	L
		FM6	0.65	L	0.73	H	0.83	L
		FM7	0.65	L	0.82	H	0.71	L
		FM8	0.96	L	0.68	H	0.81	L
		FM9	0.52	L	0.77	H	0.74	L
		FM13	0.96	L	0.14	L	0.55	L
	Runway	FM1	0.36	M	0.89	H	0.37	M

Procedure	Risk Occurrence Area	FM#	P-d.m.	l.b.	S-d.m.	l.b.	D-d.m.	l.b.
		FM2	0.65	L	0.77	H	0.29	L
		FM3	0.70	L	0.86	H	0.52	L
		FM4	0.83	L	0.95	H	0.45	L
		FM5	0.78	L	0.80	H	0.67	L
		FM6	0.65	L	0.77	H	0.48	L
		FM7	0.74	L	0.95	H	0.81	L
		FM8	0.96	L	0.73	H	0.76	L
		FM9	0.61	L	0.91	H	0.76	L
		FM10	0.65	L	0.93	H	0.64	L
		FM11	0.40	M	0.91	H	0.84	M
		FM12	0.36	M	0.95	H	0.26	M
		FM13	0.85	L	0.27	H	0.29	L
		FM14	0.65	L	0.93	H	0.52	L

Note: d.m. = degree of membership; l.b. = linguistic variable

Because the membership of moderate possibility is higher than the low one, we assume the linguistic variable here is moderate. Similarly, we repeat the Fuzzification procedure; the results are shown in Table 4.13.

Table 4.13 Membership of Linguistic Class

Input parameter	Linguistic variable	Membership
Possibility	Low	0.196
	Moderate	0.2（max）
Severity	Low	0.03
	Moderate	0.26（max）
Detectability	*Low*	0.17（max）
	Moderate	0.11

Step 3: Derivation of the fuzzy rule

Through a consensus building meeting with five experts, this study assumes fourteen fuzzy rules and these are shown in Table 4.14. For example, Rule H in Table 4.14 should be read as: If possibility is Moderate, severity is Moderate and detectability is from Law to Moderate, then the risk is Moderate.

Table 4.14 Fuzzy Rules

Rule #	Possibility	Severity	Detectability	Risk
Rule A	High	High	High, Moderate, Low	High
Rule B	High	Moderate	Moderate, High	High
Rule C	High	Moderate	Low	Moderate
Rule D	High	Low	Moderate, High	Moderate
Rule E	High	Low	Low	Low
Rule F	Moderate	High	High, Moderate, Low	High
Rule G	Moderate	Moderate	High	High
Rule H	Moderate	Moderate	Low, Moderate	Moderate
Rule I	Moderate	Low	High	Moderate
Rule J	Moderate	Low	Low, Moderate	Low
Rule K	Low	High	Moderate, High	High
Rule L	Low	High	Low	Moderate
Rule M	Low	Moderate	High, Moderate, Low	Moderate
Rule N	Low	Low	High, Moderate, Low	Low

Step 4: Evaluation to a fuzzy conclusion

Following the preceding example, Rule G, Rule H, Rule I, Rule J, Rule M and Rule N are individually matched and fired for the 6 input combinations. To determine the truth-value of the result 'Low' from rule N we note that its premise is the conjunction of the possibility = Low, severity = Low, and detectability = Low, fuzzy sets, with membership values of 0.196, 0.03 and 0.17, respectively. Thus, the conclusion, risk = Low, has a membership value of min (0.196, 0.03, 0.17) = 0.03. Similarly, we can reference the Tables 4.7-4.11 and repeat the evaluation procedure to yield all results shown in Table 4.15.

Table 4.15 Evaluation to a Fuzzy Conclusion-Example

Rule＃	Possibility/d.m.	Severity/d.m.	Detectability/d.m.	Risk	Min. Membership
Rule N	*Low/0.196*	*Low/0.03*	*Low/0.17*	*Low*	*μ(low risk)=0.03*
Rule N	*Low/0.196*	*Low/0.03*	*Moderate/0.11*	*Low*	*μ(low risk)=0.03*
Rule M	Low/0.196	Moderate/0.26	Low/0.17	Moderate	μ(moderate risk)=0.17
Rule M	Low/0.196	Moderate /0.26	Moderate/0.11	Moderate	μ(moderate risk)=0.11
Rule I	Moderate/0.2	Low/0.03	Low/0.17	Moderate	μ(moderate risk)=0.03
Rule J	*Moderate/0.2*	*Low/0.03*	*Moderate/0.11*	*Low*	*μ(low risk)=0.03*
Rule G	Moderate/0.2	Moderate/0.26	Low/0.17	High	μ(high risk)=0.17
Rule H	Moderate/0.2	Moderate/0.26	Moderate/0.11	Moderate	μ(moderate risk)=0.11

Note: d.m. = degree of membership

Step 5: Defuzzification to a crisp RPN

The degree of membership of the conclusion is sometimes interpreted as its “degree of truth”. In the preceding example, the support value at the maximal degree of membership and the truth-value of each fuzzy conclusion (see Tables 4.11 and 4.15) are the following: The maximum support-value and truth-value（degree of membership）of low risk are 0 and 0.03（μ（low risk）=max（0.03,0.03,0.03）=0.03）. The maximum support-value and truth-value（degree of membership）of moderate risk are 52 and 0.17（μ（moderate risk）=max（0.17,0.11,0.03,0.11）=0.17）. The maximum support-value and truth-value（degree of membership）of high risk are 100 and 0.17（μ（high risk）=0.17）. Hence, applying to Eq. (3), the Z value is:

$$Z = (0.03\times0+0.17\times52+0.17\times100)/(0.03+0.17+0.17)=69.83 \quad (4)$$

Similarly, we can repeat the defuzzification procedure to yield all Weighted Mean of Maximum conclusions. The Z value represents crisp ranking from the fuzzy conclusion set. We can define it as RPN, the overall results shown in Table 4.16.

Table 4.16 FMECA-Airport Airside Risk Evaluation

Procedure	Risk Occurrence Area	FM#	P	S	D	RPN	Rank	Risk Level
STANDING	Apron-Gate Area	FM2	15	10	10	13.59	76	L
	（157.58）	FM5	18	46	5	38.30	66	M
		FM6	37	34	35	69.83	29	M
		FM13	8	30	82	35.86	67	L
（365.05）	Holding Pad	FM2	14	45	8	38.59	65	M
	（207.47）	FM3	14	48	12	42.61	62	M
		FM5	12	52	6	40.31	63	M
		FM6	18	56	20	52.84	51	M
		FM13	6	30	62	33.12	69	L
PUSHBACK/	Apron-Gate Area	FM2	5	24	14	22.62	74	L
	（282.97）	FM3	16	50	24	48.99	54	M
TOWING		FM5	20	58	10	50.31	53	M
		FM6	22	62	14	55.94	48	M
		FM8	4	30	5	22.47	75	L
（282.97）		FM9	18	48	10	43.21	60	M
		FM13	6	38	64	39.43	64	M
TAXI	Taxiway System	FM2	10	72	30	61.11	43	M
	（485.86）	FM3	12	90	29	73.43	21	M
		FM5	18	84	10	64.66	39	M
		FM6	22	88	28	78.77	12	M
		FM7	12	90	8	62.11	41	M
		FM8	2	80	10	44.90	59	M
		FM9	20	92	12	71.81	23	M
		FM13	5	30	28	29.06	70	L
（1724.78）	Holding Pad	FM2	8	52	42	48.85	55	M
	（324.77）	FM3	10	86	30	69.45	30	M
		FM5	10	80	10	57.16	45	M
		FM6	18	70	20	62.05	42	M
		FM8	6	30	17	27.99	71	L
		FM9	4	48	8	33.50	68	M
		FM13	2	30	32	25.77	72	L
	Runway	FM1	15	88	22	72.08	22	M

Procedure	Risk Occurrence Area	FM#	P	S	D	RPN	Rank	Risk Level
	（914.15）	FM2	14	82	30	70.59	28	M
		FM3	16	94	24	77.19	13	M
		FM5	22	92	10	71.14	26	M
		FM6	26	92	30	84.15	10	M
		FM7	14	94	10	67.52	33	M
		FM8	2	86	12	48.43	56	M
		FM9	22	98	12	76.24	16	M
		FM10	19	98	63	92.52	9	H
		FM11	42	88	79	99.32	5	H
		FM12	43	96	58	100.00	1	H
		FM13	4	66	62	54.98	50	M
TAKEOFF	Terminal Airspace	FM1	29	92	82	97.48	7	H
	（450.07）	FM2	4	87	18	57.12	46	M
		FM3	26	98	69	98.13	6	H
（450.07）		FM4	19	92	16	73.98	18	M
		FM5	6	92	28	66.93	35	M
		FM13	4	78	30	56.43	47	M
APPROACH	Terminal Airspace	FM2	6	52	22	43.01	61	M
	（313.25）	FM3	18	98	73	93.55	8	H
		FM4	4	99	30	66.99	34	M
（313.25）		FM5	6	76	30	58.85	44	M
		FM13	4	62	48	50.84	52	M
LANDING	Taxiway System	FM2	12	88	19	68.39	32	M
	（488.49）	FM3	18	94	30	80.87	11	M
		FM5	10	90	16	66.13	36	M
		FM6	16	88	7	62.71	40	M
		FM7	16	92	12	69.45	31	M
（1542.42）		FM8	2	86	8	45.94	58	M
		FM9	22	90	11	70.90	27	M
		FM13	2	30	19	24.09	73	L
	Runway	FM1	41	95	59	100.00	1	H
		FM2	16	90	30	77.01	15	M

Procedure	Risk Occurrence Area	FM#	P	S	D	RPN	Rank	Risk Level
	（1053.93）	FM3	14	94	20	73.88	20	M
		FM4	8	98	23	71.29	24	M
		FM5	10	91	14	65.52	38	M
		FM6	16	90	22	73.96	19	M
		FM7	12	98	8	66.04	37	M
		FM8	2	88	10	48.09	57	M
		FM9	18	96	10	71.18	25	M
		FM10	16	97	15	74.27	17	M
		FM11	42	96	68	100.00	1	H
		FM12	41	98	57	100.00	1	H
		FM13	7	68	30	55.59	49	M
		FM14	16	97	20	77.10	14	M

4.4 Risk Assessment

Step 6: Generation of the weights of P, S and D

According to crisp inputs of Possibility, Severity, Detectability and crisp outputs of RPN in Table 4.16, we apply Eq. (1) to compute the corresponding weights by EXCEL formulation "LINEST". According to the Table 4.7, there are seventy-six stroke questionnaire data of state and control variables filed into Eq. (1) respectively. The next step is taking the form of natural logarithm on both sides of Eq. (1). Finally, we can acquire the weight value of decision factors and the array of statistics by using "EXCEL" application software and its multiple linear regression function i.e. LINEST. The weight value represents the importance of risk decision factors. The calibrated results and related statistics are shown in Table 4.17.

Table 4.17 Fitted Values and Statistics

Variable	Coefficient (Standard Error)	t Value
Constant	0.3597 (0.0739)	4.86*
Possibility	0.1678 (0.0099)	16.93*
Severity	0.6819 (0.0172)	39.45*
Detectability	0.1335 (0.0103)	12.92*
R^2=0.97		

Note: *represents 1% level of significance

Table 4.17 shows that the weights of Possibility, Severity, and Detectability are respectively W_p=0.1678, W_s=0.6819, W_d=0.1335 and C=e^0.3597=1.43296. The fundamental statistics analysis proceeded as follows. In Table 4.17, the estimation results show that Possibility, Severity, and Detectability are all significant at a level of 0.01 by determining the two-tailed t-test, which suggests all these three variables are the important risk decision factors. In addition, we also conclude that Severity (W_s=0.6819) plays the more important role than Possibility (W_p=0.1678) and Detectability (W_d=0.1335) in risk decision.

R^2 represents the coefficient of determination, and the validity of model fit can be estimated by R-square (R^2=0.97). From Table 4.17, the result shows that 97% of the variation of RPN can be explained by this model. This suggests the selected variables are highly related with RPN.

The weight value represents the importance of risk decision factors. In the assessment of airside risk occurred in TTIA, we conclude that severity of risk is much more important than possibility and detectability. Therefore, when planning strategies to reduce risk in the future, strategies to lower severity of risk should be considered first to have a greater impact.

Step 7: Risk assessment matrix and threshold value

To construct the TTIA Risk Assessment Matrix, we must make sure of the relationship between decision factors and their corresponding risk level first. Following the preceding example, the linguistic class of possibility, severity and detectability are moderate, moderate and low, respectively. It conforms to Rule H in Table 4.14, so we determine the risk level here is moderate. Referring to the risk level evaluation criteria, moderate risk level means the risk must be reviewed (see Table 4.11). Similarly, we compute all the risk level and complete "Risk Level" column in Table 4.16. Finally, this study derived at the TTIA-Risk Assessment Matrix as shown in Table 4.18.

Table 4.18 TTIA-Risk Assessment Matrix

		POSSIBILITY								
		L(Low)			M (Moderate)			H(High)		
S		Detect	H	***Unaccepted***	Detect	H	***Unaccepted***	Detect	H	***Unaccepted***
E	H	-ability	M	***Unaccepted***	-ability	M	***Unaccepted***	-ability	M	***Unaccepted***
V			L	**Reviewed**		L	***Unaccepted***		L	***Unaccepted***
E		Detect	H	**Reviewed**	Detect	H	***Unaccepted***	Detect	H	***Unaccepted***
R	M	-ability	M	**Reviewed**	-ability	M	**Reviewed**	-ability	M	***Unaccepted***
I			L	**Reviewed**		L	**Reviewed**		L	**Reviewed**
T		Detect	H	Accepted	Detect	H	**Reviewed**	Detect	H	**Reviewed**
Y	L	-ability	M	Accepted	-ability	M	Accepted	-ability	M	**Reviewed**
			L	Accepted		L	Accepted		L	Accepted

Table 4.18 shows that the risk level increased from the lower-left side (accepted risk) to the upper-right side (unaccepted risk). Although airport operators can identify the risk categorization by possibility, severity and detectability through Risk Assessment Matrix, the sequential improvement of risk items with same risk categorization cannot be determined exactly without the RPN. In addition, based on the information in Table 4.16, this study finds that the highest 9 risks all corresponds to unacceptable risk category, and their RPN are form 92.52 to 100. Hence, the threshold value between reviewed and unacceptable risk can be assumed as 92.52. Similarly, this study can determine the threshold value between reviewed risk and acceptable risk, shown in Table 4.19.

Table 4.19 Threshold Value of the Risk Assessment Matrix

Threshold value	Risk Level	Code	Meaning
92.52≦RPN	High risk	H	Risk is unacceptable
38.3≦RPN＜92.52	Moderate risk	M	Risk must be reviewed
RPN＜38.3	Low risk	L	Risk is acceptable

The threshold value in Table 4.19 shows that if RPN is less than 38.3, the risk is acceptable. If RPN is between 38.3 and 92.52, the risk must be reviewed at all time. Otherwise, if RPN is more than 92.52, the risk is unacceptable and should take improvement measures to lower the risk to a reasonably practicable (ALARP) level.

4.5 Results Analysis

We can easily analyze the airport airside risk utilizing our fuzzy assessment system described in previous sections. Table 4.1 shows the airside-related risks in TTIA; Table 4.16

shows “runway incursion-animal at runway in the landing procedure” is the most critical risk, and the airport operator must take improvement measures to lower the risk to reasonably practicable (ALARP) extent immediately. The other unaccepted risks in TTIA are “runway incursion-animal at runway in the taxi procedure”, “abnormal runway contact at terminal airspace in the takeoff procedure”, “runway incursion-vehicle, a/c or person at runway in the landing and taxi procedure” in order. Those unaccepted risk are summarized and shown in Table 4.20.

Table 4.20 Unaccepted Risks in TTIA Airport Airside

Risk code	Description (Risk Item -Area- Procedure)
R1	Runway excursion at runway in the taxi procedure.
R2	Runway incursion-animal at runway in the taxi procedure.
R3	Runway incursion-vehicle, a/c or person at runway in the taxi procedure.
R4	Abnormal runway contact at terminal airspace in the takeoff procedure.
R5	Air traffic management at terminal airspace in the takeoff procedure.
R6	Air traffic management at terminal airspace in the approach procedure.
R7	Abnormal runway contact at runway in the landing procedure.
R8	Runway incursion-animal at runway in the landing procedure.
R9	Runway incursion-vehicle, a/c or person at runway in the landing procedure.

Moreover, referring to the threshold value in Table 4.19, the highest 9 risks whose RPN are more than 92.52 are determined as unacceptable risks; the TTIA operator must pay more attention to reduce those risks in order. Similarly, the lowest 9 risks are acceptable risks and the rest other 59 risks are necessary be reviewed at all time. In addition, easing the severity of risk should be considered first to have a greater achievement because of the most critical importance of it ($W_s = 0.6819 > W_p = 0.1678 > W_d = 0.1335$). In order to make further analysis of risk pattern, this study compiles statistics from Table 4.16 by risk category, occurrence area and flight operation procedure and shown in Tables 4.21-4.23. The frequency is the count number of all happened risk items; the aggregate RPN is the RPN sum of specific risk item and the average RPN is the aggregate RPN divided by the frequency.

Table 4.21 TTIA Airside Risk Items-RPN List

Risk Items	Frequency	Aggregate RPN	Avg. RPN
ARC	3	269.56	89.85
ADRM	10	500.87	50.09
ATM	9	658.12	73.12
CFIT	3	212.26	70.75
F-NI	10	579.30	57.93
RAMP	8	514.62	64.33
GCOL	4	265.12	66.28
ICE	6	237.82	39.64
LOC-G	6	366.85	61.14
RE	2	166.79	83.40
RI-A	2	203.02	101.51
RI-VAP	2	202.98	101.49
SEC	10	405.18	40.52
USOS	1	77.10	77.10

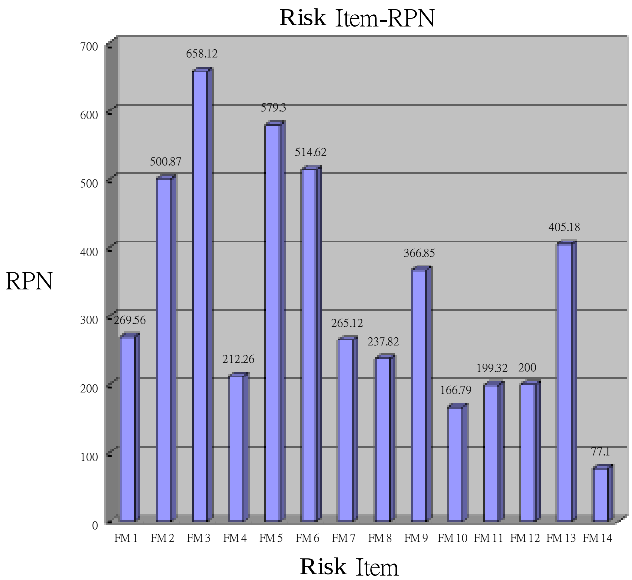


Figure 4.3 TTIA Airside Risk Items-RPN Chart

Table 4.21 and Figure 4.3 show that aerodrome (ADRM), fire/smoke (F-NI), and security related (SEC) are the most 3 frequent risks with occurrence frequency=10, and “ATM” accounts for 14.14% (RPN=658.12) of total risk (RPN=4661.61), while runway incursion-animal (RI-A) is the biggest single risk item (RPN=101.51).

Table 4.22 TTIA Airside Occurrence Areas-RPN List

Occurrence Area	Aggregate RPN
Apron-Gate Area	414.92
Holding Pad	532.24
Taxiway System	974.35
Runway	1968.08
Terminal Airspace	763.32

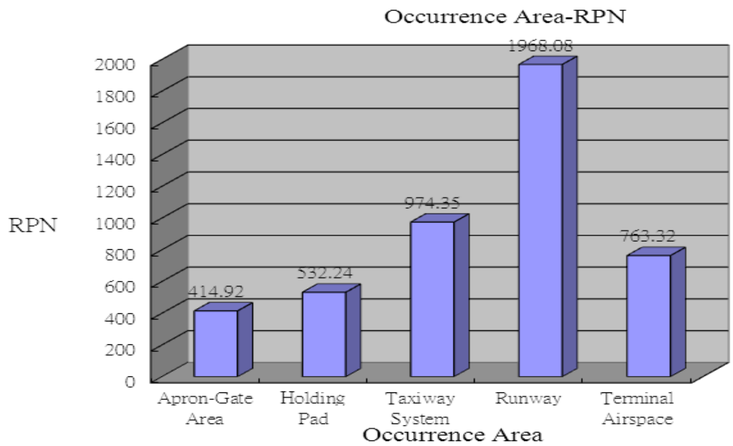


Figure 4.4 TTIA Occurrence Areas-RPN Chart

Table 4.22 and Figure 4.4 show that "Runway" is the most risky area in the TTIA airside, accounts for 42% of total risk. The risk ranking of other TTIA airside area is "Taxiway System", "Terminal Airspace", "Holding Pad" and "Apron-Gate Area" in order.

Table 4.23 TTIA Airside Flight Operation Procedures- RPN List

Procedure	Aggregate RPN
STD	339.43
PBT	282.97
TXI	1724.78
TOF	450.77
APR	313.25
LDG	1542.42

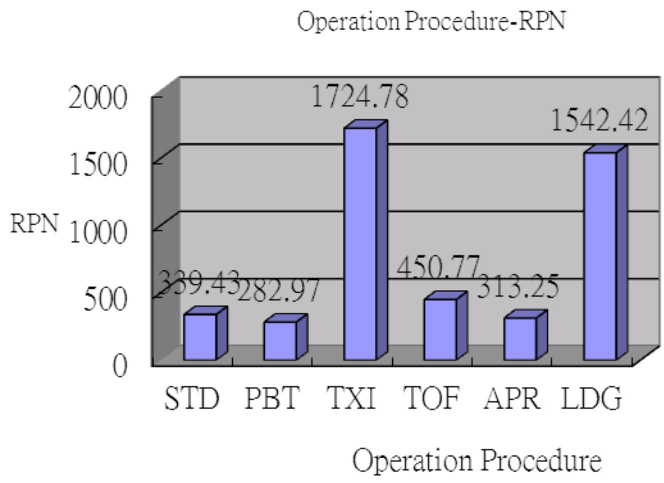


Figure 4.5 TTIA Airside Operation Procedures- RPN Chart

Regarding the flight operation procedure where risks occurred, Table 4.23 and Figure 4.5 show that procedures on taxi (TXI) is the most dangerous stage, accounting for 37% of total risk, followed by procedures on landing (LDG). These two flight operation procedures contribute to 71% of the total risk. The risk ranking of other flight operation procedures in TTIA is takeoff (TOF), standing (STD), approach (APR) and pushback/towing (PBT).

Based upon the analysis by risk category, occurrence area and flight operations procedures above, we determine that “RI-A” is the biggest single risk item, “Runway” is the most risky area and “TXI”, and “LDG” are the most dangerous stage in TTIA. This result conforms to the overall analysis conclusion that the greatest risk is “runway incursion –animal at runway in the landing procedure” (see Table 4.16).

CHAPTER 5. ANALYSIS OF IMPROVEMENT MEASURES

5.1 Development of Improvement Measures

The last stage of airport safety management is risk improvement. In this stage, the airport operator may deploy some improvement measures by effectively prioritizing the related airport airside risks. Due to limited resources, how to decide the improvement sequence from the alternative measures for reducing the related risk level is also important. After the airport airside risk analysis including risk identification, risk measurement and risk assessment accomplished in previous chapters (see step1~step7), following procedures (step8~step9) would be proceeded to propose and prioritize improvement measures in this chapter.

Step 8: Improvement measures

According to the TTIA airport airside risk evaluation results shown in Table 4.16, this study extracts nine unaccepted risks from the eighty two potential risk items and shown in Table 4.20. Under the premise that TTIA airside risks were explored and assessed by the previous study, this research intends to propose some improvement measures to eliminate the unacceptable potential risks through the in-depth interviews with related experts. After a series of discussions and in-depth interviews through the MOTC officer, CAA officer, ASC flight safety division director, TTIA safety director and China Airlines senior pilot. They are all safety-related experts with years' experience and this study proposes some concrete improvement measures developed from the areas of management, operation and facility. Those improvement measures are planned from the perspectives of management, operation and facility respectively to ease the level of those unacceptable risks to the reviewed or even acceptable extent. Those specific improvement measures are summarized and listed in Table 5.1.

Table 5.1 Improvement Measures.

	Management	Operation	Facility
R1	Strengthening the runway inspection mechanism.	Providing the runway more detailed real-time information (Such as slippery road surface level).	Enhancing the runway pavement, runway alignment indicator lights system and providing the runway center line lights.
R2	Setting up the wildlife control working group and establishing the Standard Operating Procedure.	Increasing the frequency of inspections and maintenance.	Enhancing the runway foreign object damage (FOD) detection equipment, construction fence and bird striking warning radar.
R3	Enhancing the employee assessment, workshops and SMS Meeting.	Strengthening the employee operational training in airside.	Providing the operation vehicle with Automatic Dependent Surveillance-Broadcast (ADSB), Airport Surface Detection Equipment (ASDE) and navigation aids facilities.
R4	Strengthening the Tail Strike Avoidance Recognition training mechanism.	Providing air traffic controllers with real-time information of the runway, rewriting the Aircraft Communication Addressing and Reporting System (ACARS) Loadsheet and notifying pilots by Automatic Terminal Information Service (ATIS) system.	Upgrading the runway detection equipment and air navigation aids facilities.
R5	Strengthening the employee training of communication.	Enhancing the capacity of the air traffic control (ATC) systems and increasing the establishment of air traffic controllers.	Enhancing dynamical flight information in a real-time system.
R6	Strengthening the employee training of communication.	Enhancing the application of flight dynamical information and increasing the establishment of air traffic controllers.	Upgrading navigation communicating systems.

R7	Improving the Bounce Landing Recovery Procedure to increase the possibility of detection (POD) and decrease the possibility of false detection (POF).	Improving the pilot skill of FLARE timing, GO-Around and cross-wind landing.	Improving the runway facilities and low level wind shear alert system (LLWAS).
R8	Monitoring and supervising the runway system at all times.	Improving fence inspection and implementing wildlife control.	Improving the runway foreign object damage (FOD) detection systems and bird striking warning radar.
R9	Strengthening penalties in regulations and enhancing monitoring the progress of the aircraft and traffic.	Strengthening the airside employee training and assessment in communications and flight deck duties.	Providing the operation vehicle with Automatic Dependent Surveillance-Broadcast (ADSB), Airport Surface Detection Equipment (ASDE) and foreign object damage (FOD) detection systems.

After a further analysis, this study generalizes that risk generate circumstances are somewhat overlapped from the nine unaccepted risks listed in Table 4.20. Table 5.2 shows the characteristic of similarities and overlaps among those unaccepted risks.

Table 5.2 Similarities and Overlaps of Unaccepted Risks

Circumstance	Category	Amount
Flight Procedure	Taxi	3
	Takeoff	2
	Approach	1
	Landing	3
Occurrence Area	Runway	6
	Terminal Airspace	3
Risk Item	Runway Excursion	1
	Runway Incursion-Animal	2
	Runway Incursion-Vehicle, A/C or Person	2
	Abnormal Runway Contact	2
	Air Traffic Management	2

Owing to the fact that improvement measures are proposed in light of the characteristics of risk circumstance based on flight procedures, occurrence areas and risk items, the homogeneous nature of risk circumstance causes improvement measures are similar to some extent. To be simplified and implemented effectively, this study integrates those improvement measures in Table 5.3 according to category of management, operation and facility.

Table 5.3 Integrated Improvement Measures

Measure	Management	Operation	Facility
1	M1: Setting up the wildlife control working group and establishing the Standard Operating Procedure.	O1: Providing air traffic controllers with real-time information of the runway, rewriting the Aircraft Communication Addressing and Reporting System (ACARS) Loadsheet and notifying pilots by Automatic Terminal Information Service (ATIS) system.	F1: Enhancing the runway pavement, runway alignment indicator lights system and providing the runway center line lights.
2	M2: Enhancing the employee assessment, workshops and SMS Meeting.	O2: Improving the pilot skill of FLARE timing, GO-Around and cross-wind landing.	F2: Providing the operation vehicle with Automatic Dependent Surveillance-Broadcast (ADSB) and navigation aids facilities.
3	M3: Improving the Bounce Landing Recovery Procedure to increase the possibility of detection (POD) and decrease the possibility of false detection (POF).	O3: Improving fence inspection and implementing wildlife control.	F3: Upgrading the runway detection equipment, Airport Surface Detection Equipment (ASDE) and air navigation aids facilities.

5.2 Improvement Measures Analysis and Prioritization

Those improvement measures above-mentioned in step 8 were developed according to the TTIA characteristics and essence of each risk item deliberately. Each of them has been examined in detail in order to avoid doing any improvement measure to reduce some of the risk level but increased others. Improvement works are budgetary limited by TTIA operator depending on the cost.

Step 9: Improvement measures analysis and prioritization

Considering that funding and budgetary resource are limited, this study applies the concept of QFD-phase1-HOQ mentioned in section 2.4.2 to prioritize the proposed improvement measures. The improvement measure ranking procedure was illustrated and showed in Table 5.4. The step-by-step process of proceeding Table 5.4 is as follows.

Step A: Whats/ Customer Requirements - "Voice of the Customer"

The previous researches in this study have already summarized nine unacceptable risks in TTIA airside through the due risk assessment processes. In this study, those unaccepted risks are considered as what need to be improved that is "Voice of the Customer" in HOQ. Owing to that the importance of each decision factor (i.e. W_p, W_s and W_d) is different; those unacceptable risks could be classified by possibility, severity and detectability to appear the difference of improvement efficiency.

Step B: Whys/ Customer Importance Ratings-"Risk Importance (%)"

This step includes "Risk Value" which is the RPN value of each unaccepted risk shown in Table 4.16 and "Weight Scale" which is the weight of decision factor (i.e. W_p, W_s and W_d). The importance of each requirement in the relationship matrix could be rated here. The weight scale reflects the importance of decision factors which are possibility, severity and detectability computed in section 4.1. The matrix computation process for Risk Importance (%) in this research performed as follows.

Suppose the matrix A is a column matrix and given by:

$A= [\text{ Risk Value }]_{27x1}$

Suppose the matrix B is a row matrix and given by:

$B= [\text{ Weight Scale }]_{1x27}$

The product of A and B will be a matrix with 27 rows and 27 columns. Then it can be diagonallized and defined as matrix C. Matrix C is a column matrix with 27 rows and given by:

diag (AB)=C

The diag function is used to either construct a diagonal matrix from a vector, or return the diagonal elements of a matrix as a vector. The "diag" here is used to extract a diagonal as matrix C from a matrix of the product of A and B.

Suppose the matrix C' is a column matrix and given by:

$C'= [\text{ Risk Importance }]_{27x1} = C/\det(A^T B^T)$

Transposition is producing the transpose of a matrix A^T which is computed by swapping columns for rows in the matrix A. The transpose A^T of a matrix A can be obtained by reflecting the elements along its main diagonal. The determinant of a matrix A is denoted det (A). To calculate the determinant of a matrix is denoted by surrounding the matrix entries by vertical bars instead of the brackets or parentheses of the matrix.

Step C: Hows/ Technical Descriptors – "Voice of the Engineer"

In this research, the technical descriptors are those improvement measures classified by possibility, severity, and detectability and proposed in Table 5.3 to satisfy the risk improvement needs (Voice of the Customer). Those proposed improvement measures were created to meet customer needs i.e. easing the unacceptable risk level.

Step D: Whats vs. Hows/ Relationship Matrix

The relationship matrix in this research is where the determinations of the relationship between unacceptable risks and improvement measures. It was filled with discrete numbers between 0 and 9 to indicate whether the interaction of the specific item is a strong positive, a weak positive, or somewhere in between. Those discrete numbers decided by expert experience indicated the correlationship between risk items and improvement measures. By discussing with experts, this research acquires the "Whats vs. Hows" average value of matrix numbers between risk items and improvement measures shown in Table 5.4.

Step E: How Muches/ Absolute Importance-"Measures Score and Rating"

Finally, the numerical calculation of the absolute importance for each improvement measure is the product of the cell value and the risk importance rating. Numbers are then added up in their respective columns to determine the importance for each improvement measures. Additional annexes on the right side and bottom hold the "Whys-risk importance which is the percentage of the product of RPN and weight scale" and the "How Muches-improvement measures score and rating". Rankings based on the Whys and the correlations can be used to calculate priorities for the Hows. The matrix computation process for "Measures Score" in this research performed as follows.

Suppose the matrix D is a matrix with 27 rows and 9 columns. It denotes "Whats vs. Hows" and given by:

$D = [\text{Whats vs. Hows}]_{27x9}$

The transpose of a matrix D denoted by D^T is a matrix with 9 rows and 27 columns given by:

$D^T = [\text{Hows vs. Whats}]_{27x9}$

The product of D^T and C' denotes "Measure Score" and defined as matrix E. Matrix E is a column matrix with 9 rows and given by:

$E = [\text{Measure Score}]_{9x1} = D^T C'$

To fit the format of Table 5.4, the transpose of a matrix E denoted by E^T is a row matrix with 9 columns. The elements of matrix E^T are numbers representing measures score of nine improvement measures. Finally, this research acquires the measures rating by prioritizing the values of measures score.

Table 5.4 Prioritized Improvement Measures

Risks \ Measures		Management			Operation			Facility			Risk Priority		
		M1	M2	M3	O1	O2	O3	F1	F2	F3	Risk Value	Weight Scale	Risk (%) Importance
POSSIBILITY	R1	4	5	2	0	1	6	7	6	4	100	0.1678	1.93720
	R2	8	6	5	4	0	1	0	5	4	100	0.1678	1.93720
	R3	0	8	6	2	5	3	6	8	0	100	0.1678	1.93720
	R4	4	5	5	8	2	4	1	1	9	100	0.1678	1.93720
	R5	0	0	1	0	1	3	5	6	5	99.32	0.1678	1.92403
	R6	6	3	3	3	0	5	1	6	0	98.13	0.1678	1.90097
	R7	6	1	9	1	7	0	4	6	1	97.48	0.1678	1.88838
	R8	5	1	0	2	4	9	6	1	5	93.55	0.1678	1.81225
	R9	4	4	5	5	3	0	1	2	0	92.52	0.1678	1.79230
SEVERITY	R1	5	4	5	5	5	4	6	0	4	100	0.6819	7.87232
	R2	9	5	3	0	0	3	0	2	4	100	0.6819	7.87232
	R3	1	7	0	6	6	1	1	9	4	100	0.6819	7.87232
	R4	6	5	5	8	1	1	5	5	8	100	0.6819	7.87232
	R5	5	4	4	3	1	4	0	6	5	99.32	0.6819	7.81879
	R6	3	3	4	2	5	0	5	3	4	98.13	0.6819	7.72511
	R7	5	4	8	1	7	4	3	3	2	97.48	0.6819	7.67394
	R8	5	5	5	6	2	8	4	3	6	93.55	0.6819	7.36456
	R9	4	4	2	1	2	3	6	1	5	92.52	0.6819	7.28347
DETECTABILITY	R1	4	5	6	3	4	5	8	1	6	100	0.1335	1.54122
	R2	2	4	0	4	6	2	0	2	2	100	0.1335	1.54122
	R3	3	9	4	1	1	1	6	7	6	100	0.1335	1.54122
	R4	2	3	1	9	6	2	1	1	4	100	0.1335	1.54122
	R5	2	0	6	1	5	1	3	3	6	99.32	0.1335	1.53074
	R6	0	0	2	3	6	4	6	6	5	98.13	0.1335	1.51240
	R7	4	0	8	3	8	6	5	5	1	97.48	0.1335	1.50238
	R8	4	4	6	5	4	7	2	5	4	93.55	0.1335	1.44181
	R9	3	3	1	2	4	3	4	2	5	92.52	0.1335	1.42593
Measures Score		438	422	397	342	334	319	341	375	436	Risk improvement scale from 0 to 9(weak to strong)		
Measures Rating		1	3	4	6	8	9	7	5	2			

5.3 Results Analysis

Table 5.4 applies the HOQ diagram to resemble a house, used for defining the relationship between unaccepted risk items and proposed improvement measures. It is a part of the QFD and it utilizes a planning matrix to relate what the risk item wants to how an improvement measure is going to meet those wants. It looks like a house with a "correlation matrix" as its roof, unaccepted risks versus proposed improvement measures as the main part. It is based on the belief that improvement measures should be proposed to decrease the level of risk items. Table 5.4 takes "Whats-unaccepted risks classified by possibility, severity and detectability" as the labels on the left and "Hows-improvement measures" across the top. The body of the house is a matrix of "Whats vs. Hows" filled with discrete numbers between 0 and 9 to indicate whether the interaction of the specific item is a strong positive, a weak positive, or somewhere in between. Those discrete numbers decided by expert consensus indicated the correlationship between risk items and improvement measures. The risk value is the RPN value of each unaccepted risk shown in Table 4.16. To appear the importance of decision factor, those unaccepted risks are categorized into areas of possibility, severity and possibility. The weight scale is decided by the weight of decision factor (i.e. W_p, W_s, and W_d). The risk importance is the product percentage of risk value and weight scale. The measures score is the product of the cell value and the risk importance rating. Numbers are then added up in their respective columns to determine the importance for each improvement measures. Additional annexes on the right side and bottom are the "Risk Importance (%)", "Weight Scale", "Measures Score" and "Measures Rating". The weight scale reflects the importance of decision factors which are possibility, severity and detectability computed in section 4.1. Rankings based on the Whys and the correlations can be used to calculate priorities for the Hows.

Table 5.4 also shows that the ability to decrease those unaccepted risks within the nine proposed improvement measures are followed by M1,F3,M2,M3,F2,O1,F1,O2 and O3. The improvement measure "Setting up the wildlife control working group and establishing the Standard Operating Procedure." shows the greatest improvement scale while the improvement measure "Improving fence inspection and implementing wildlife control." shows the least. Top five of which have been focused on measures of management and facility facets, we can infer that management and facility improvement measures may be more effective to improve the risk level than operation does. The inefficiency of operation improvement measures may result from the perfection of implementation before. That's makes it leave little room for improvement. If we take a further look at the value of "measure/risk correlation" which is greater than four, it can be observed that "M1" is the greatest improvement measure in severity (six risk scenarios), while "O3" is the least improvement measure in severity (one risk scenario). The phenomenon is not observed in accordance with the areas of possibility and detectability. This result matches the deduction of section 4.1 that strategies to lower severity of risk should be considered first to have a greater impact. This conclusion can be used as an improved policy formulation reference.

CHAPTER 6. CONCLUSIONS AND FUTURE STUDIES

This chapter begins with a conclusion of the study and its major findings, and ends with suggestions for future studies.

6.1 Conclusions

Four major findings are concluded as follows:

1. Identification of the airside risk items

This study first extracts six airport airside-related flight operation procedures and their corresponding occurrence areas based on fourteen flight operation procedures and twenty-eight categories of accidents in ICAO aviation accidents data base (ICAO, 2010). It then identifies fourteen airport airside-related risk items such as ARC, ADRM, ATM, CFIT, F-NI, RAMP, GCOL, ICE, LOC-G, RE, RI-A, RI-VAP, USOS and SEC through expert in-depth interviews.

2. Critical risk items through risk assessment

To process the airport airside risk management systematically, a framework of fuzzy logic-based FMECA technique was developed in this study and applied to analyze a case study of TTIA airside risk using vague, qualitative or imprecise information. This study quantifies the airport airside risks and constructs the RAM for TTIA. The approach presented resolves the issues of weighting of risk factors and the threshold value in risk assessment matrix, and concludes that there are nine unacceptable risks in TTIA. Among them, "runway incursion-animal at runway in the landing procedure" is the most critical risk item; "runway" is the most risky area; and "TAXI" is the most risky flight operation procedure as well. We also conclude that risk is unacceptable if its RPN is more than 92.52; and "severity" is the most critical factor to eliminate the risk.

3. Generation of improvement measures

Under the premise that TTIA airside risks were explored and assessed by the previous study, this study proposes twenty-seven improvement measures (shown in Table 5.1) to eliminate the unacceptable potential risks through the in-depth interviews with related experts. Those improvement measures are planned from the perspectives of management, operation and facility respectively and be integrated in Table 5.3 according to their homogeneous nature of risk circumstance.

4. Prioritization of improvement measures

To rank those improvement measures more efficiently, this study goes even further to incorporate them according to the categories of management, operation and facility as some more representative improvement measures. Finally, this study applies the concept of QFD to generate and prioritize the nine proposed improvement measures mentioned above and finds that the improvement measure "setting up the wildlife control working group and establishing the Standard Operating Procedure." shows the greatest improvement scale while the improvement measure "improving fence inspection and implementing wildlife control." shows the least. In addition, improvement measures from the categories of management and facility may be more effective to improve the risk level than operation does. This result also matches the deduction of section 4.4 that strategies to lower severity of risk should be considered first to have a greater impact.

6.2 Contributions

This study may have some contributions to the existing literature on the following aspects:

1. Identify the airport airside risks

Most of past researches in aviation safety focused on the safety of aircraft operation, traffic control system, crew management, and logistics issues etc. Less attention has been paid on airport risk management, and few studies explored the airport airside risk systematically as well. While different airport may confront different risk situation, the specific risk identification plan must be taken for each airport. This study identifies the TTIA airport airside risks from the categories of flight operation procedures, occurrence areas and risk items by ICAO (2010) through the expert in-depth interviews.

2. Develop a system framework of risk assessment through the FLC-based FMECA

Few studies quantified the airport airside risks under the condition of only few aviation accident cases. This research tries to apply the possibility concept of fuzzy theory and FLC method to assess the airport airside risks through the framework of FMECA. The proposed FLC-based FMECA model may improve the shortcomings of traditional RPN by incorporating weights of decision factors and this model exhibits the following advantages. First, the fuzzy inference provides more realistic and flexible way to reflect the real situation of the ambiguous airport airside risk with imprecise information. Second, the weights of risk decision factors can be employed to implement improvement strategies in the future. Third, ambiguous risk can be effectively ranked and represented according to the precise RPN. Finally, by designing FMECA table systematically and assessing RPN, we can explore the hot spot of airport airside risk occurrence efficiently.

3. Construct the RAM and find out the threshold value of risk levels

The RAM provides a systematic method for assigning a risk level to a failure mode based on the possibility, severity and detectability of the occurrence. Because the causes of airport airside risk are very complicated, mapping RAM traditionally is rough and unable to define the existing risk threshold value of RAM objectively. This study applies the FLC-based FMECA framework and fuzzy rules to construct the RAM of TTIA and determine its threshold value more precisely. In addition, the airport operator may explore unacceptable risk more efficiently by precise threshold value of RAM.

4. Propose and prioritize improvement measures

Specific improvement measures, preventive controls or recovery measures should be put to ease the airport airside risk level, while few literatures discussed the airport improvement measures systemically. Under the premise that airport airside risks were explored and assessed by the previous study, this research then proposes some tailored improvement measures to eliminate the potential risks through both document analyses and in-depth-interview with some airport safety experts. Besides, this study applies the QFD concept to prioritize those proposed improvement measures. As well as, the empirical case study of TTIA in this study demonstrates the superiority of the proposed models in exploring potential risks and prioritizes some proposed improvement measures. The results have provided useful directions for the decision makers of airports to implement risk improvement projects efficiently and systematically. This conclusion can be used as a reference for policy formulation.

6.3 Directions for Future Studies

Owing to the scarcity of aviation occurrence, few quantitative accident data could be applied in the airport airside risk analysis. This study attempts constructing a systematic process and building a system framework to analyze the airport airside risks from the airport operator's viewpoint through the FLC-based FMECA and QFD concept. If there is more statistic information of aviation accident, some directions for future studies can be developed as follows:

1. Further studies could be undertaken to analyze the failure mode effects on each risk item in detail.
2. Implementing a scenario analysis to predict if those unaccepted risks can be effectively transfer to the level of reviewed or even accepted risks by the implementation of improvement measures.
3. As there may be some extent of correlationship between those proposed improvement measures, further study can apply the HOQ roof analysis to precede with integrated improvement measures.
4. While budgets may be a critical consideration for decision makers, it is recommended that further studies incorporate the budget limits in the prioritization of improvement measures.
5. This research discusses airport airside risk management based on the viewpoint of the airport operator; further research may explore this issue from the perspective of aircrafts or pilots.

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APPENDIX I IN-DEPTH INTERVIEW -- RISK ASSESSMENT

一、專家組成

編號	單位	年資	職責
1	交通部	15	飛航安全及飛航標準政策
2	民航局	18	（一）飛航管制 （二）儀航程序 （三）航空情報 （四）航空通信 （五）航空氣象 （六）飛航服務安全查核 （七）助導航設施適航查核、驗證及飛航測試
3	飛安會	8	飛安改善、事故調查
4	機場公司	5	機場安全管理
5	中華航空	16	航空器駕駛

二、問卷說明

任何的飛安事故皆可能導致令人無法逆料的致命損失，且經統計有近八成的意外發生在機場。因此，如何有效的識別飛安風險，進而客觀的衡量其風險值並建立相關風險評估矩陣將是機場安全管理的首要之務。而建立系統性的機場風險管理機制以有效的監管和改善飛安風險，亦為降低飛安潛在風險並實現機場安全目標的唯一途徑。

為研析機場飛航安全議題，本研究以臺灣桃園國際機場(TTIA)為例，採用國際民用航空組織(ICAO)航空事故資料庫中對各飛航程序及相關風險因子的定義及分類，找出該機場不可接受的風險項目，並進行各項風險分析與衡量作業，希望能提供機場管理者一個有效且系統性的風險管理決策參考。

本次訪談部分內容將以腦力激盪的形式進行，以下將逐步進行本研究的各項議題探討，您的回答及寶貴意見將對本研究之風險評估有很大的助益，另本研究僅做整體政策規劃分析之用，不會披露您個人資料，非常感謝您的協助。

三、訪談內容

第一階段:構建機場空側風險分析架構

國際民用航空組織(ICAO)航空事故資料庫中對各飛航程序的分類有Approach、Emergency Descent、En Route、Initial Climb、Landing、Maneuvering、Post-Impact、Pushback/Towing、Standing、Takeoff、Taxi、Uncontrolled Descent及Unknown等13個階段,各飛航階段在和機場空側有關的介面,可能發生Abnormal runway contact、Ground handling等28種不同的風險事件(詳Table A.1.4),請各位依Table A.1.1格式,參照Table A.1.2至Table A.1.4的分類,就TTIA的特性共同討論擬定, 首先找出和機場相關的Flight procedure,再從這些Flight procedure中找出可能和機場空側相關的Area,並進一步檢視Table A.1.4中每一Flight procedure與機場空側相關的Area內可能產生的Risk item。

Table A.1.1 Airport Airside Risk Items.

Flight procedure	Risk occurrence area	Failure mode (risk item)

Table A.1.2 Procedure of Flight Abbreviatons

Abbreviation	Procedure
APR	Approach
EMG	Emergency Descent
ENR	En Route
ICL	Initial Climb
LDG	Landing
MNV	Maneuvering
PIM	Post-Impact
PBT	Pushback/Towing
STD	Standing
TOF	Takeoff
TXI	Taxi
UND	Uncontrolled Descent
UNK	Unknown

Table A.1.3 Airport Airside Area

Holding Pad	Apron-Gate	Taxiway	Runway	Terminal Airspace

Table A.1.4 Risk Item and Definition

Risk Item	Definition
ARC	Abnormal runway contact (Any landing or takeoff involving abnormal runway or landing surface contact.)
ADRM	Aerodrome (Aerodrome design, service, or functionality issues are evident.)
ATM	Air traffic management (ATM) or communications/navigation/ surveillance (CNS) service issues are evident.
CFIT	Controlled flight into or toward terrain (In-flight collision or near collision with terrain, water, or obstacle without indication of loss of control.)
F-NI	Fire/smoke (non-impact) (Fire or smoke in or on the aircraft, in flight or on the ground, which is not the result of impact.)
RAMP	Ground handling (Occurrences during or from ground handling operations.)
GCOL	Ground collision (Collision while taxiing to or from a runway.)
ICE	Icing (Accumulation of snow, ice, or frost on aircraft surfaces that adversely affects aircraft control or performance.)
LOC-G	Loss of control - ground (Loss of aircraft control while the aircraft is on the ground)
RE	Runway excursion (A veer off or overrun off the runway surface)
RI-A	Runway incursion - animal (Collision with, risk of collision, or evasive action taken by an aircraft to avoid an animal on a runway in use.)
RI-VAP	Runway incursion - vehicle, a/c or person (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.)
SEC	Security related (Criminal/Security acts, which result in accidents or incidents.)
USOS	Undershoot/overshoot (A touchdown off the runway surface.)
AMAN	Abrupt Maneuver (The intentional abrupt maneuvering of the aircraft by the flight crew.)
CABIN	Cabin Safety Events (Miscellaneous occurrences in the passenger cabin of transport category aircraft)
EVAC	Evacuation (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 was a factor in the outcome.)
F-POST	Fire/Smoke (Post-Impact: Fire/Smoke resulting from impact.)
FUEL	Fuel Related (One or more powerplants experienced reduced or no power output due to fuel exhaustion, fuel

	starvation/mismanagement, fuel contamination/wrong fuel, or carburetor and/or induction icing.)
LOC-I	Loss of Control - Inflight (Loss of aircraft control while inflight.)
LALT	Low Altitude Operations (Collision or near collision with obstacles/objects/terrain while intentionally operating near the surface (excludes takeoff or landing phases).)
OTHR	Other (Any occurrence not covered under another category.)
SCF-NP	System/Component Failure or Malfunction (Non-Powerplant: Failure or malfunction of an aircraft system or component - other than the powerplant.)
SCF-PP	System/Component Failure or Malfunction (Powerplant: Failure or malfunction of an aircraft system or component - related to the powerplant.)
TURB	Turbulence Encounter (In-flight turbulence encounter.)
USOS	Undershoot/Overshoot (A touchdown off the runway surface.)
UNK	Unknown or Undetermined (Insufficient information exists to categorize the occurrence.)
WSTRW	Windshear or Thunderstorm (Flight into windshear or thunderstorm.)

第二階段:語意風險程度構建

本階段的目的在於構建 Possibility、Severity、Detectability 及 Risk Level 之語意風險程度函數，將各語意風險程度分為 High、Moderate、Low 三等級(個語意等及特性詳 Table A.1.5)，請您填答各等級語意範圍的上、下界值，個語意值應為介於 0 至 100 間之整數，請注意各語意尺度順序的合理性，並依序填入下列各表中。

Table A.1.5 Linguistic Level Evaluation Criteria

類別	語意層級	定義
Possibility	High	Repeated failures
	Moderate	Occasional failures
	Low	Relatively few failures
Severity	High	Serious property loss or death
	Moderate	Property loss or life injury
	Low	Slight property loss
Detectability	High	Failure is hardly detected
	Moderate	Failure may be detected
	Low	Failure is easily be detected
Risk Level	High	Unacceptable risk
	Moderate	Reviewed risk
	Low	Acceptable risk

Table A.1.6 Possibility Linguistic Level

語意程度	High	Moderate	Low
(上界值,下界值)	(,)	(,)	(,)

Table A.1.7 Severity Linguistic Level

語意程度	High	Moderate	Low
(上界值,下界值)	(,)	(,)	(,)

Table A.1.8 Detectability Linguistic Level

語意程度	High	Moderate	Low
(上界值,下界值)	(,)	(,)	(,)

Table A.1.9 Risk Level Linguistic Level

語意程度	High	Moderate	Low
(上界值,下界值)	(,)	(,)	(,)

第三階段:構建 Possibility,Severity,Detectability,Risk Level 語意風險值

本階段的目的在於了解各專家對 TTIA 各項空側風險程度的經驗衡量值，各風險衡量值應為介於 0 至 100 間之整數，請依第一階段構建的 Table A.1.1 架構，分別對各情境風險之 Possibility、Severity、Detectability 進行風險值評估，並依序填入下表:

Table A.1.10 Assessment Value of Possibility, Severity and Detectability

Procedure	Risk Occurrence Area	Risk Item	Possibility	Severity	Detectability
STANDING	Apron-Gate Area	ADRM			
		F-NI			
		RAMP			
		SEC			
	Holding Pad	ADRM			
		ATM			
		F-NI			
		RAMP			
		SEC			
PUSHBACK/ TOWING	Apron-Gate Area	ADRM			
		ATM			
		F-NI			
		RAMP			
		ICE			
		LOC-G			
		SEC			
TAXI	Taxiway System	ADRM			
		ATM			
		F-NI			
		RAMP			
		GCOL			
		ICE			

Procedure	Risk Occurrence Area	Risk Item	Possibility	Severity	Detectability
		LOC-G			
		SEC			
	Holding Pad	ADRM			
		ATM			
		F-NI			
		RAMP			
		ICE			
		LOC-G			
		SEC			
	Runway	ARC			
		ADRM			
		ATM			
		F-NI			
		RAMP			
		GCOL			
		ICE			
		LOC-G			
		RE			
		RI-A			
		RI-VAP			
		SEC			
TAKEOFF	Terminal Airspace	ARC			
		ADRM			
		ATM			
		CFIT			
		F-NI			
		SEC			

Procedure	Risk Occurrence Area	Risk Item	Possibility	Severity	Detectability
APPROACH	Terminal Airspace	ADRM			
		ATM			
		CFIT			
		F-NI			
		SEC			
LANDING	Taxiway System	ADRM			
		ATM			
		F-NI			
		RAMP			
		GCOL			
		ICE			
		LOC-G			
		SEC			
	Runway	ARC			
		ADRM			
		ATM			
		CFIT			
		F-NI			
		RAMP			
		GCOL			
		ICE			
		LOC-G			
		RE			
		RI-A			
		RI-VAP			
		SEC			
		USOS			

第四階段: 構建 Fuzzy Rules

為了解各專家對 TTIA 空側風險的邏輯規則，本研究以 Possibility、Severity、Detectability 為輸入的狀態變數，Risk Level 為輸出的控制變數，並以 High、Moderate、Low 為語意等級進行規則庫的建置，請各位依專業知識與經驗共同討論完成下列模糊邏輯資料庫。

Table A.1.11 Fuzzy Rules

Rule Number	IF(狀態變數)			THEN(控制變數)
變數	Possibility	Severity	Detectability	Risk
語意程度 (High、Moderate、Low)				

APPENDIX Ⅱ IN-DEPTH INTERVIEW -- IMPROVEMENT MEASURES

一、專家組成

編號	單位	年資	職責
1	交通部	18	飛航安全及機場發展
2	民航局	20	（一）飛航管制政策 （二）機場發展規劃 （三）飛航安全改善
3	飛安會	12	飛安改善、事故調查
4	機場公司	13	機場安全管理督導
5	中華航空	21	飛行員教官

二、問卷說明

任何的飛安事故皆可能導致令人無法逆料的致命損失，且經統計有近八成的意外發生在機場。因此，如何建立系統性的機場風險管理機制以有效的監管和改善飛安風險，實為降低飛安潛在風險並實現機場安全目標的唯一途徑。

為研析機場飛航安全議題，本研究以臺灣桃園國際機場(TTIA)為例，採用國際民用航空組織(ICAO)航空事故資料庫中對各飛航程序及相關風險因子的定義及分類，並依相關專家意見及本研究發展之風險評量模式，衡量出該機場空側不可接受的風險項目及程度，在此，希望能藉由各位專家的寶貴意見研擬並排序出具體可行的改善策略，提供機場管理者一個有效且系統性的風險管理決策參考。

本次訪談部分內容將以腦力激盪的形式進行，以下將逐步進行本研究的各項議題探討，您的回答及寶貴意見將對本研究之風險評估有很大的助益，另本研究僅做整體政策規劃分析之用，不會披露您個人資料，非常感謝您的協助。

三、訪談內容

第一階段:研提機場空側風險改善措施

本研究藉由前期研究，綜整相關專家意見並應用風險分析工具，找出 9 項臺灣桃園國際機場(TTIA)空側無法接受且須立即改善的風險，如下表:

Table A.2.1 Unaccepted Risks in TTIA Airport Airside

Risk code	Description (Risk Item -Area- Procedure)
R1	Runway excursion at runway in the taxi procedure.
R2	Runway incursion-animal at runway in the taxi procedure.
R3	Runway incursion-vehicle, a/c or person at runway in the taxi procedure.
R4	Abnormal runway contact at terminal airspace in the takeoff procedure.
R5	Air traffic management at terminal airspace in the takeoff procedure.
R6	Air traffic management at terminal airspace in the approach procedure.
R7	Abnormal runway contact at runway in the landing procedure.
R8	Runway incursion-animal at runway in the landing procedure.
R9	Runway incursion-vehicle, a/c or person at runway in the landing procedure.

本研究擬從管理面(Management)、營運面(Operation)及設施面(Facility)三個面向來規劃風險管理措施，以下我們將就 Table A.2.1 所列風險逐一進行討論，希望能借重各位先進的專業及經驗找出具體可的風險改善措施。

Table A.2.2 風險改善措施建議表

風險類別(R1~R9)	改善措施
管理面(Management)	
營運面(Operation)	
設施面(Facility)	

第二階段: 風險改善措施排序

本研究第一階段已逐項針對 TTIA 不可接受風險，就管理面、營運面及設施面研提出 27 項改善措施(詳 Table A.R2.1)，經考量部分措施所因應的風險種類、發生地及飛航階段有部分重疊，本研究進一步將上述改善措施依其特性簡併如下表 Table A.2.3，以利後續方案排序作業。

Table A.2.3 Concise Improvement Measures

Measure	Management	Operation	Facility
1	M1: Setting up the wildlife control working group and establishing the Standard Operating Procedure.	O1: Providing air traffic controllers with real-time information of the runway, rewriting the Aircraft Communication Addressing and Reporting System (ACARS) Loadsheet and notifying pilots by Automatic Terminal Information Service (ATIS) system.	F1: Enhancing the runway pavement, runway alignment indicator lights system and providing the runway center line lights.
2	M2: Enhancing the employee assessment, workshops and SMS Meeting.	O2: Improving the pilot skill of FLARE timing, GO-Around and cross-wind landing.	F2: Providing the operation vehicle with Automatic Dependent Surveillance-Broadcast (ADSB) and navigation aids facilities.
3	M3: Improving the Bounce Landing Recovery Procedure to increase the possibility of detection (POD) and decrease the possibility of false detection (POF).	O3: Improving fence inspection and implementing wildlife control.	F3: Upgrading the runway detection equipment, Airport Surface Detection Equipment (ASDE) and air navigation aids facilities.

藉由QFD概念可將顧客需求轉換成服務技術，本研究將降低風險視為顧客需求，各項風險改善措施則係為了降低風險而設計的策略，透過風險因子與風險改善措施關係矩陣，進行以QFD為概念的運算，進行各項風險改善措施效力排序，可作為機場管理者採行各項風險改善措施之參考依據，考量各改善措施可能對各改善風險項目的Possibility、Severity及Detectability有不同程度的改善，為呈現其改善幅度，Table A.2.4左側為依據Possibility、Severity及Detectability設計之各項需改善風險因子，上方列則為依據Management、Operation及Facility面項分類之改善措施，請各位先進就專業經驗根據矩陣內每一項目的關聯性給予強度上的評估，以瞭解各項目間的關聯性與重要性，評比數據為介於0至9之間之整數，關聯性越強數字越大，請依序填列下表。

Table A.2.4 風險因子-風險改善措施關係矩陣

Measures / Risks		Management			Operation			Facility		
		M1	M2	M3	O1	O2	O3	F1	F2	F3
POSSIBILITY	R1									
	R2									
	R3									
	R4									
	R5									
	R6									
	R7									
	R8									
	R9									
SEVERITY	R1									
	R2									
	R3									
	R4									
	R5									
	R6									
	R7									
	R8									
	R9									
DETECTABILITY	R1									
	R2									
	R3									
	R4									
	R5									
	R6									
	R7									
	R8									
	R9									

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Qualifications

Sep. 2006 – Feb. 2015 National Chiao Tung University Taiwan
Ph.D. in Transportation and Logistics Management

May. 2004 – Aug. 2004 Word Trade Instituteation Switzerland
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Master Degree Program in World Trade Law

Sep. 1995 – Jul. 1997 National Chiao Tung University Taiwan
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Sep. 1991 – Jul. 1995 National Cheng Kung University Taiwan
Bachelor of Transportation and Communication Management

Research Interests

- Transportation Economics
- International Trade Law
- Trade Negotiation and Litigation
- Micro and Macro Economics
- Navigation Management
- Fuzzy Theory
- Risk Management
- Performance Evaluation
- Operations Research

Work Experience

2001 – current
Ministry of Transportation and Communications

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Institute for Chinese Meteorology and Environment R&D Center

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Publications

Refereed Papers:

- Feng, C. M. and Chung, C. C. (2000), "Analyzing Risks Caused by Government to Private Investor in BOT Transportation Project.", Transportation Planning Journal, vol.29, no.1, pp. 79-108.
- Feng, C. M. and Chung, C. C. (2013), "Assessing the Risks of Airport Airside through the Fuzzy Logic- Based Failure Modes, Effect and Criticality Analysis.", Mathematical Problems in Engineering, Volume 2013 (2013), Article ID 239523, 11 pages (SCI).
- Chung, C. C., Yeh, H. H. and Chen, C. T. (2012), "Energy Consumption Analysis of MRT System and Suggestion.", Railway Operations and Management, vol.8, pp. 88-112.

Conference Papers:

- Feng, C. M. and Chung, C. C. (2011) ," Airport Risk Assessment through FMECA and Fuzzy Logic Control ", The 2011 World Conference of Air Transport Research Society, Sydney, Australia, June 29 – July 2, 2011.