國立成功大學

交通管理科學研究所

碩士論文

臺灣民用遙控無人機安全管理策略評估之研究

The Evaluation of Civil Drone Safety Management Strategies in Taiwan

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中華民國 108 年 6 月

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摘要

近年來，由於民用遙控無人機的所帶來的經濟及社會效益越來越廣泛，加上其入手容易，使其於民間之使用日趨頻繁，然而無人機闖入禁航區或是墜落導致人員財產損害等飛行意外事故的頻傳也造成民眾的恐慌。為保障飛航及民眾安全，總統於 2018 年 4 月 25 日公布《民用航空法》修正案，正式將遙控無人機納入管理，預計於 2019 年 7 月 1 日正式實施，然而，由於執行上的困難，使民航局將實施日期延期至 2020 年。此外，2019 年 3 月至 4 月期間，台北松山機場發生兩起遙控無人機闖入機場事件，造成許多旅客權益受損，更影響飛安。因此，遙控無人機的安全管理迫在眉睫，唯有透過妥善且有效的策略管理遙控無人機，才能讓政府與產業界達到雙贏的局面。

本研究係以提升民用遙控無人機之安全與可靠度水準為目標，希冀能降低無人機的違規事件及安全事故。透過蒐集文獻及專家問卷，結合模糊層級分析法，以及重要度可行性分析，以獲取當前須優先執行的策略，此外，本研究應用 0-1 目標規劃以進一步分析在時間、人力、經費等資源限制的情況下，對於策略選擇的影響，以更貼近實務上的考量。

研究結果顯示，本研究共篩選出 13 項策略，而整體專家認為各構面的重要度依序是「安全政策與目標」、「安全提升與教育」、「安全風險管理」及「安全保證」; 而最須優先執行的四項策略分別是「設定安全績效目標」、「確保法規體系能與國際接軌」、「指派測驗及給證之權責單位」及「推廣安全教育課程」。而本研究透過情境模擬之分析結果發現，即便受到時間、人力與經費等資源限制，「設定安全績效目標」、「整合遙控無人機資訊管道」、「推廣安全教育課程」仍會被選擇執行，未來民航局可利用本研究之模型，依其資源限制之變動，而選擇最佳之管理策略。

關鍵字：遙控無人機; 模糊層級分析法; 重要度可行性分; 0-1 目標規劃

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Abstract

With the economic and social benefits, the uses of drones have increased in recent years. However, the occurrences, involving prohibited area incursion or damage to personnel and property, have also increased. To guarantee the public safety, the Civil Aviation Act was amended on April 25, 2018, and policies were planned to be implemented on July 1, 2019. Nevertheless, with the difficulty of execution, the execution date is postponed to the year 2020. Furthermore, the Taipei Songshan airport was closed for a while because of the incursion of a drone in March and April in 2019. The measures of drone management must be taken as soon as possible.

The aim of this research is to improve the safety and reliability level of drones. The top priority strategies are obtained through literature review, experts' questionnaire, the fuzzy analytic hierarchy process, and importance-achievability analysis. In addition, to be more practical, the zero-one goal programming is further applied to analyze the effects on the selection of strategies in the scenarios of resource constraints, such as time, manpower, and budgets.

There are four dimensions and thirteen strategies suggested for drone management. The strategies in the top priority implementation zone are "set safety performance targets", "gear regulations to the international conventions", "assign testing and certificating authorities", and "promote drone education programs". In addition, in scenario analysis, despite of the limitation on time, manpower, and budget, some strategies are still selected, including "set safety performance targets", "integrate drone information system", and "promote drone education programs".

Key words: Drone; Fuzzy Analytic Hierarchy Process (FAHP); Importance-Achievability Analysis (IAA); Zero-One Goal Programming (ZOGP)

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從大學到研究所，來到成大已經六年了，這段期間經歷了很多事情，也認識很多人，更從大家身上學到很多，真的很感謝大家！

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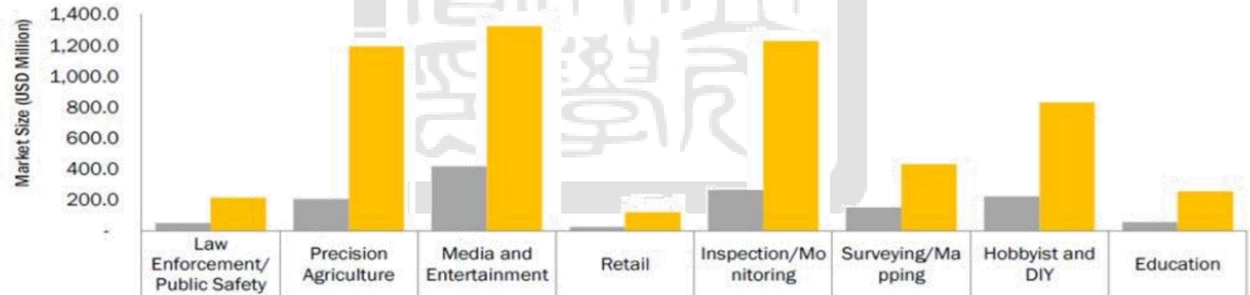
Chapter 1 Introduction

1.1 Research Background and Motivation

It has been seen the rapid developments in the area of drones, which also refers to unmanned aerial vehicles (UAV), unmanned aircraft systems (UAS), or remotely piloted aircrafts (RPA). Owing to the continuous technological innovation, drones are no longer used only for the military. Instead, drones become powerful and popular business tools.

With a variety of shapes and sizes, drones can carry different payloads, and are used by operators for different purposes. MarketsandMarkets (2015) forecasts that in 2020 the application in media and entertainment will have the largest market share with the compound annual growth rate (CAGR) of 26%. More details are shown in Figure 1-1:



	Law Enforcement/ Public Safety	Precision Agriculture	Media and Entertainment	Retail	Inspection/Monitoring	Surveying/Mapping	Hobbyist and DIY	Education
2015	49.3	204.9	416.8	24.0	262.6	149.9	221.9	55.0
2020	212.9	1,193.5	1,323.8	119.7	1,228.9	430.8	831.3	254.2
CAGR % (2015-2020)	33.99%	42.25%	26.00%	37.89%	36.16%	23.50%	30.23%	35.81%

Figure 1-1 Global drones market size, by application, 2015-2020 (in USD million). Source: MarketsandMarkets (2015).

What's more, as regards the geographical distribution of drones worldwide, in 2018, the Americas (USA, Canada, Mexico, and Brazil) is the area expected to account for the highest share of the global commercial drones market, followed by Asia-Pacific (APAC), Europe, and the rest of the world (RoW).

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Table 1-1 Global drones market size, by region, 2014-2020 (USD Million)

	Americas	Europe	APAC	RoW	Total
2014	467.4	129.3	85.9	43.6	725.2
2015	896.9	234.1	172.9	80.6	1,384.5
2016	1,449.4	355.7	291.6	128.2	2,224.9
2017	2,026.6	465.9	423.6	176.2	3,092.1
2018	2,580.0	553.4	558.0	219.5	3,910.9
2019	3,134.6	624.5	698.7	260.7	4,718.5
2020	3,744.6	689.5	857.2	303.9	5,595.2
CAGR (2015-2020)	33.09%	24.12%	37.74%	30.39%	32.22%

Source: MarketsandMarkets (2015).

The use of drones has been increasing throughout the world year by year. By the end of May 2017, more than 772,000 drone owners had already registered with the Federal Aviation Administration (FAA) and Figure 1-2 shows the trend for growth of drone owners in the US. Based on this trend, the FAA (2018a) also forecasts that the number of drones identified as model aircrafts will likely double in the next 5 years, from the present 1.1 million to over 2.4 million. As shown in Table 1-2, the high/optimistic scenario of this growth may be as high as 3.17 million, while the low scenario shows it could be about 1.96 million.

In addition, drones have demonstrated a variety of applications, including crop planting, infrastructure establishment, search/rescue mission, environmental research, and many other applications which are often described as being too dull, dirty, dangerous, or demanding for conventionally piloted aircraft (CPA).

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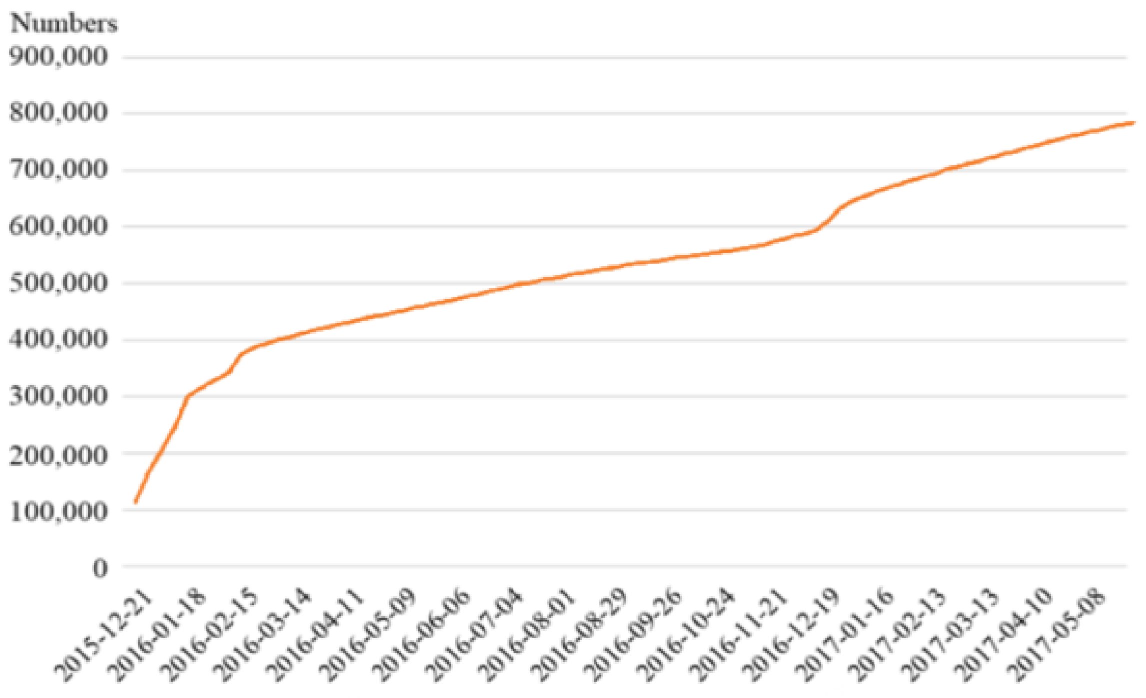

Figure 1-2 Number of registrations of drones by week (cumulative)

Source: FAA (2018a).

Table 1-2 Forecast of the number of drones in the US (millions)

	2017	2018	2019	2020	2021	2022
Low	1.10	1.50	1.76	1.87	1.92	1.96
Base	1.10	1.60	2.00	2.20	2.30	2.40
High	1.10	1.73	2.35	2.73	2.94	3.17

Source: FAA (2018a).

According to Goldman Sachs Research (2016), between 2016 and 2020, there would be a $100 billion market opportunity for drones. Among them, 70% would come from the military demand, 17% would come from the consumer demand, and 13% would come from the commercial and civil government demand.

It is very clear that drones are expanding beyond flying vehicles, which has raised additional safety, privacy, data protection, and ethical issues. Drones bring new risks to people and property on the ground as well as to the aviation industry. In particular, potential mid-air collisions pose a threat to passenger aircrafts. According

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to European Aviation Safety Agency (EASA) (2017a), the European Central Repository (ECR) had identified 606 occurrences from 2012 to 2016, of which 37 had been classified as accidents, and none of the accidents involved fatalities. By combining the data from the ECR and EASA, an increasing number of occurrences involving drones had hit the aviation world from 2012 to 2016 in Europe as shown in Figure 1-3.

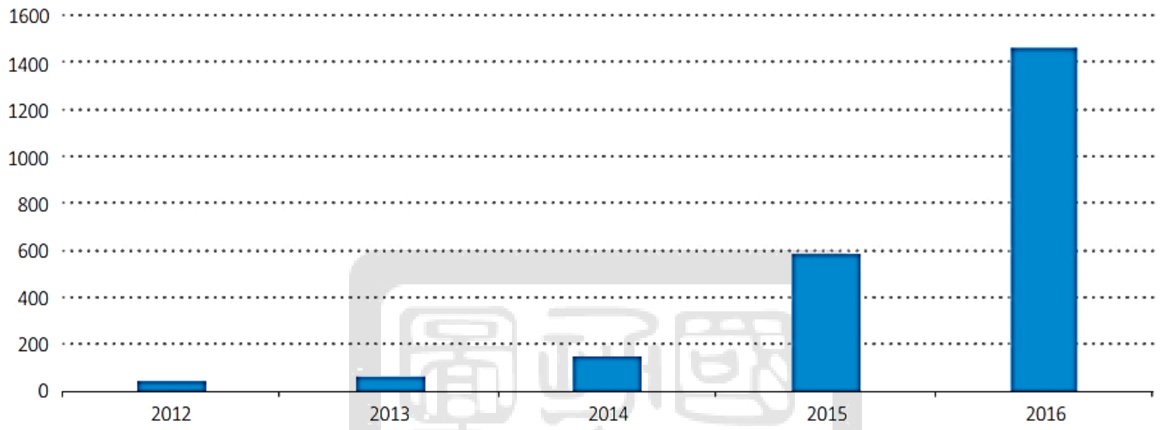

Figure 1-3 Drones reported occurrences per year, 2012-2016

Source: EASA (2017a).

This trend also appears in Taiwan. In 2015, a drone hit Taipei 101 because of operational error, which caused great panic among the public. What's worse, according to the civil aeronautics administration (CAA), the number of reported occurrences of releasing objects considered hazardous to flight safety around the airports has increased year by year since 2015.

Drones are inherently dangerous, and measures are desperately needed to ensure public safety. Besides, drones are designed to carry cameras, and the common use of drones is to gather visual images and video, which represents a new and substantial threat to behavioral privacy. There have been several incidents related drones around the world. For instance, about 11,000 people were stuck at the Gatwick airport because drones were seen on the runway between 19 and 21 December 2018. (BBC,

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2018).

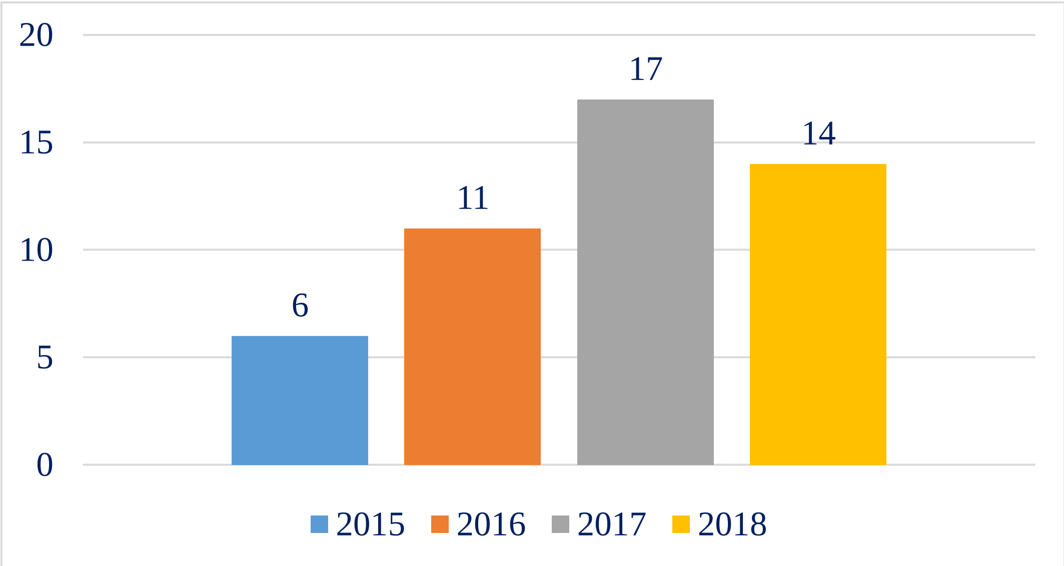

Figure 1-4 The number of reported occurrences of releasing objects considered hazardous to flight safety around the airports in Taiwan, 2015-2018

Source: CAA (2019).

Unfortunately, regulatory adaptation is far slower than technological and economic change. In Taiwan, the Civil Aviation Act was amended and announced on April 25, 2018. The amendment in other related regulations and the practice of enforcement are still in progress. The original implementation date was July 1, 2019. However, because of the difficulty of the execution, the CAA announces the postpone of the date to 2020. During this time, drones have been seen in the Songshan airport and caused an immediate shutdown of the airport for times. The police still haven't caught the perpetrators. As a result, to prevent the similar incidents from occurring or even worsen in Taiwan, the aim of this research is to discover the drone management strategies, and analyze the priority of the management strategies.

1.2 Research Objectives

This research looks into the management issues of drones which the government should deal with. With these goals, the purpose of this research is as follows:

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1. Exploring the drone management strategies by literature review, and adjusting them through the expert questionnaires.
2. Evaluating the priority of the drone management strategies through the expert questionnaires, and comparing the viewpoints of the industry, government, and academia.
3. Evaluating the resources allocation in different scenarios to make the most use of the resources on the strategies.

1.3 Research Scope

To achieve the objectives mentioned above, this research identifies and constructs the framework of drone management strategies in the view of the government authorities through literature review. Furthermore, there are two-step questionnaires distributed in this research. The first-stage questionnaire is used to filter the factors and adjust the statement of each strategy. The fuzzy analytic hierarchy process (FAHP) and importance-achievability analysis (IAA) are used to assess the priority of drone management strategies. Last but not least, the zero-one goal programming (ZOGP) is conducted to provide the reasonable resource allocation. These findings are intended to provide a useful reference for the related authorities.

1.4 Research Procedure

Figure 1-5 indicates the process in this research. This research starts with background research and literature review. Through these steps, the drone safety management strategies will be found out. These strategies will be examined by experts. With the suggestions from the first-stage questionnaire, the revised drone safety management strategy framework will be formulated. The survey will be conducted for collecting opinions from government officials, scholars, and drone

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development associations experts in Taiwan. The data collected will be analyzed to evaluate the relative importance through the FAHP. IAA will be carried out accordingly to prioritize the strategies. Last but not least, the ZOGP will be conducted to evaluate the resource allocation in each simulation scenario.

The overall conclusion, contributions, and suggestions will be presented in the end of this research as shown in Figure 1-5.

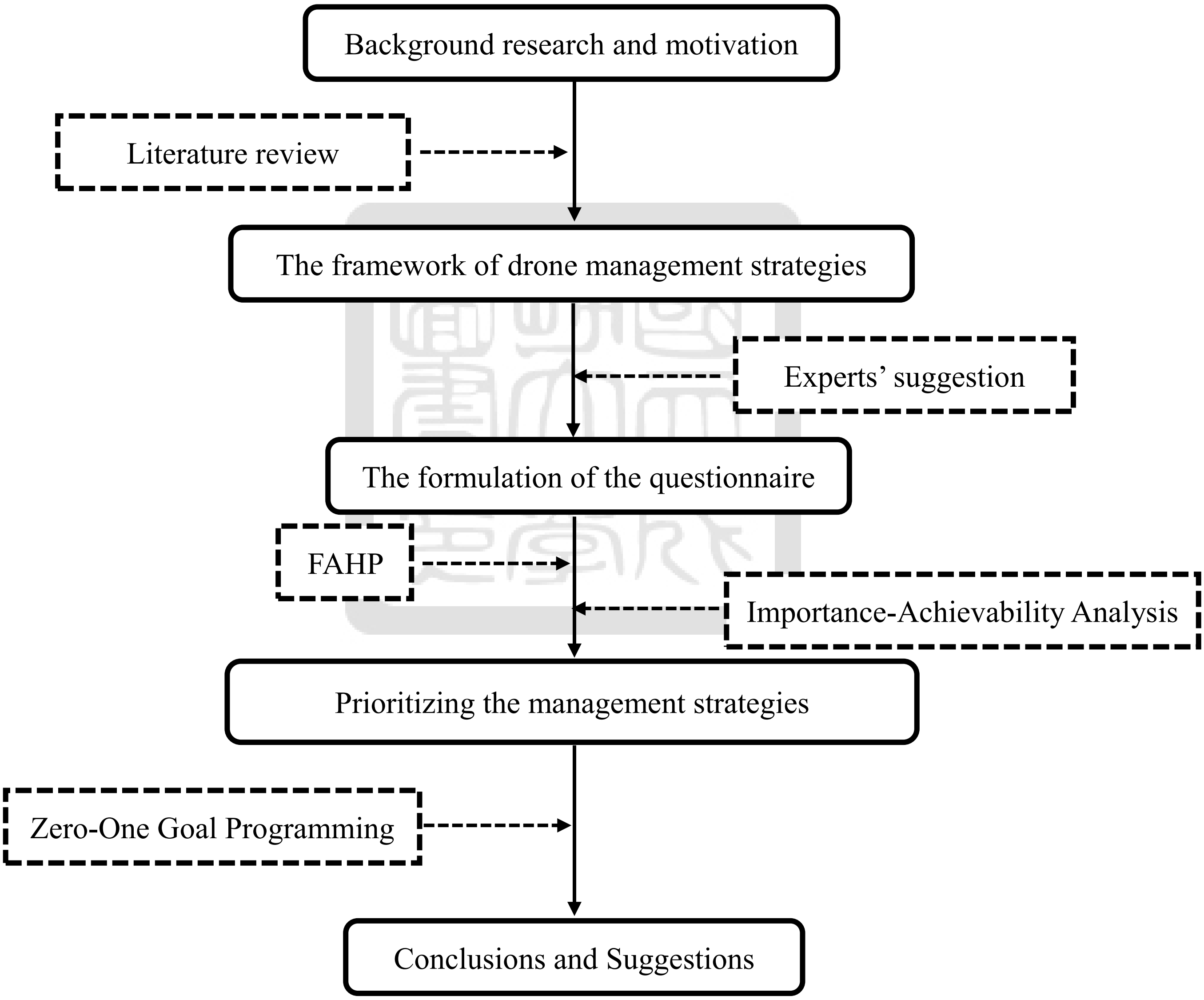

Figure 1-5 Research Procedure

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Chapter 2　Literature Review

This chapter provides a introduction of drone management. Not only will the definition and basic information of drone management be provided, but also the review of drone management policies around the world will be listed clearly. After reviewing drone management practice conducted around the world and the suggestions in other research, the framework of drone management strategies will be established.

2.1 Introduction to Drones

2.1.1 Drone

Drone is the common language of all types of aircraft without a pilot on board and their ancillary components, such as a control station, if applicable. In addition to the common term "drone", other terms and acronyms, such as Unmanned Aerial Vehicles (UAV), Unmanned Aircraft System (UAS), Remotely Piloted Aircraft (RPA), and Remotely Piloted Aircraft Systems (RPAS), are also widely used in publications.

To begin with, any aircraft intended to be flown without a pilot on board is referred to in the Convention on International Civil Aviation, signed at Chicago on 7 December 1944 and amended by the international civil aviation organization (ICAO) assembly as a "pilotless aircraft". Today we call these aircraft "unmanned" rather than "pilotless". Unmanned aircraft (UA) includes a broad spectrum from meteorological balloons that fly freely to highly complex aircraft piloted from remote locations by licensed aviation professionals. The latter are part of the category referred to as "remotely piloted aircraft" or RPA that operates as part of a system, a remotely piloted aircraft system (RPAS). (Figure 2-1)

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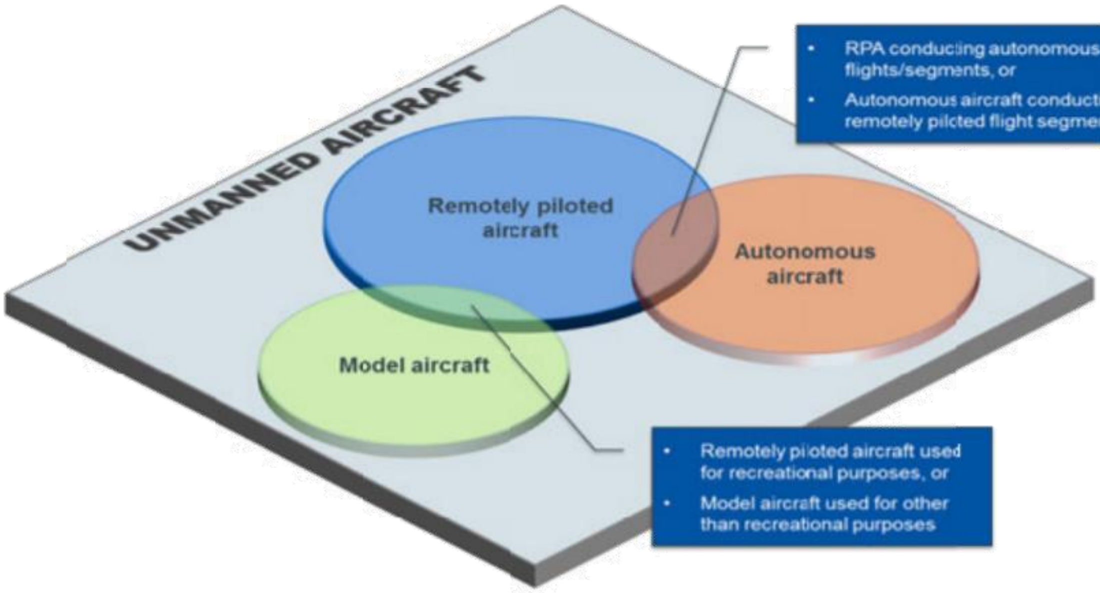

Figure 2-1 Classification of unmanned aircraft

Source: ICAO (2015).

Taiwan uses the term “drone”. In Taiwan, “drone” means the unmanned aerial vehicle, the flight control of which is operated by way of signal link through remote control device or which is operated by autopilot, or the other aircraft without human pilot aboard as announced by CAA (CAA, 2018).

In the US, FAA uses the term “unmanned aircraft” and defines as “an aircraft operated without the possibility of direct human intervention from within or on the aircraft.”

At the European Union (EU) level, no uniform terminology is used to denote what is commonly known as drones. The European Parliament uses the term “civil drones” to differentiate civilian drones from those intended for military purposes. The European Commission uses the term “remotely piloted aircraft systems” (RPAS). The EASA, an EU body established in 2002 with the mandate to issue implementing rules and approve airworthiness standards, defines “drone” as an aircraft without a human pilot on board, whose flight is controlled either autonomously or under the remote control of a pilot on the ground or in another vehicle. This term also includes machines that are normally not perceived by the general public as aircraft, such as

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flying toys, small tethered balloons, or kites. The EASA uses the term "drones" in all its communications to the general public (Levush, 2016).

2.1.2 An Overview of the Development of Drones

Drones were first conceptualized in the Civil War. They essentially consisted of loading up balloons with explosives, and users hoped that they would land on their intended targets. Missile technology had improved significantly by World War II, but unmanned aircrafts were still in their infancy. The US used planes instead of balloons. Pilots would fly the plane to a certain point, where they would bail out safely, and then a nearby aircraft would control the unmanned plane via radio control to its target.

Since the 1940s, UAVs continued to be developed by the military and have been used in multiple wars for reconnaissance missions; photography and video were integral to their operation, including surveillance of people and their movements.

Recently, because of the technological developments and decreasing costs, drones have expanded the civilian market enormously. This includes the development of commercial applications for drone use, including agriculture, oil/gas, media, real estate, and filmmaking. Drones also have increasing value for emergency services where they enable close view without putting people at risk, like in police search and rescue operations in inaccessible regions, bushfires, and assessment of unstable buildings or accident sites.

However, regulation of drone use has been slower to develop than the market and is still arguably playing catch-up. It leads to some incidents or accidents, which can be prevented beforehand, around the world.

2.1.3 An Overview of the Uses of Drones

To establish a more comprehensive understanding on the effects of drone use, the capabilities of drones will be discussed first. What drones are able to carry decides the capabilities of drones. Equipment, such as video cameras, monitoring devices,

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loudspeakers, liquid sprayers, accelerometers, GPS, and light emitting devices, is commonly mounted on drones to provide drones with more functions. The advantage of using drones is that they perform certain tasks more efficiently and accurately than human beings and traditional devices. More importantly, drones are able to carry out tasks at places which are inaccessible to human beings. Specifically, drones are being used increasingly in a wide range of fields, which include but are not limited to:

1. Agricultural Services

Drones can be used for a wide variety of agricultural services, ranging from precisely spraying pesticides and fertilizers, monitoring crops growth, estimating yields to detecting and, mitigating disease (Du & Heldeweg, 2017). Compared with conventional airplanes, drones are suitable for all sizes of crop fields and farms and are expected to provide more accurate and efficient services. For instance, in French, an agricultural technology company found that over a period of 3 years, in 627 fields of oilseed rape, farmers used on average 34 kilograms less nitrogen fertilizer per hectare than they would without the survey data. This saved on average €107 (US$115) per hectare per year (King, 2017).

2. Inspection and Monitoring

Drones are used for various types of inspections, such as for infrastructures, pipelines, and the atmosphere. The main advantages of using drones are they are much less costly and can avoid human beings from undertaking inspections in dangerous places. (Du & Heldeweg, 2017).

3. Surveillance

Drones have been widely used for surveillance and law enforcement activities undertaken by governmental authorities, in particular police and intelligence agencies. Such activities include, for instance, monitoring public events, border controls against illegal cultivation and investigation of crimes. Surveillance drones are often equipped

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with cameras and sensors for observation and data collection. In addition to continuously collecting tremendous amount of information in wide areas, surveillance drones may also be able to identify signals, objects and people, and to report the information which is considered abnormal (Du & Heldeweg, 2017). For instance, the third division, the seventh special police corps, national police agency had utilized drones in Changhua, Yunlin and Chiayi to perform aerial surveillance operations and conduct illegal investigations (Yang, 2017).

4. Search and Secure

Search and Secure drones are utilized for searching and providing aid to people that are in distress or imminent danger. For instance, drones can provide rapid and highly efficient services after an earthquake. Drones are able to search victims in an extensive area within a very short period of time and, depending on the load capability, possibly supply stranded victims with water and medicines, thereby winning time for rescue crew. Another application of drones relating to search and secure is that small autonomous drones can be sent prior to search and secure crew to an unfamiliar architecture for exploring and memorizing the structure of the architecture, and then fly back to the entrance to guide search and secure crew in the architecture.

5. Picturing and Filming

Installed cameras enable drones to take pictures and films for construction planning, geo-mapping and entertainment industry. Drones are used in construction and infrastructure asset management to capture images and to collect data. Until now, manual planning and documenting can only be done on the ground, and hiring helicopters to take images is to costly or logistically impossible due to airspace restrictions. In comparison, small drones can fly lower and closer to objects than helicopters and are able to take very detailed pictures, though they are also required to abide by relevant rules and regulation. Regarding geo-mapping, the advantages of

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using drones are similar with the case of construction planning and documenting. Without doubt, the use of drones greatly expands the creativity of photo-shooting and filming (Du & Heldeweg, 2017).

6. Parcel Delivery

The idea of using drones for delivering parcels was initiated by Amazon, a U.S. e-commerce giant, with an aim to largely saving delivery cost and increasing working efficiency. In December 2016, Amazon air delivery, for the first time, has been completed in the UK. In China, parcel delivery by drones is expected to largely improve the efficiency and decrease the cost of delivery in rural areas, in particular mountainous and hilly areas. In September 2015, Japan conducted the first flight test of drones to transport goods and drugs, and flew back and forth for a total of 20 kilometers, setting the farthest drone delivery record in Japan (Yang, 2017).

During the twentieth century, drones were almost exclusively used for military needs, peaking in the 1990s after the first Gulf War (Nonami, 2007). By contrast, in the twenty-first century, drones have been rapidly seen in the civil applications. Moreover, it has even been said that "we are entering the drone age" (Anderson, 2012). Drones are being used by crisis response and humanitarian organizations, for conservation activities, by police and other authorities, by protesters, for recreational purposes, including "drone racing", and for various commercial purposes. In addition, drones are increasingly being used as "big data" platforms, capturing multiple types of data from a range of sensors, including optical cameras, temperature sensors, GIS sensors, as well as others, and these data are increasingly being integrated with external data sources (Finn & Donovan, 2016).

2.1.4 An Overview of the Issues of Drones

However, instead of bringing convenience, drones also raise concerns about safety, security, privacy, data protection, and the environment. These concerns will be

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discussed respectively.

1. Safety and Security

As there is no pilot to be injured in a crash, drones are commonly considered to be safer for the user than piloted aircrafts (Jones et al., 2006). However, being pilotless, drones can be more vulnerable than piloted aircrafts (Lee et al., 2013), and unlike the traditional model aircraft user community, people with little or no aviation experience or knowledge are beginning to fly drones. People might be injured on the ground. Rotary wing devices may be more dangerous than fixed wing devices in cases of engine failure as they tend to fall vertically, whereas fixed wing devices can glide to the ground.

As a result, Yen (2016) and Chen (2015) suggested all drone pilots should purchase liability insurance. Du & Heldeweg (2017) also recommended to establish the drone practicing field. In fact, DJI has established a drone arena in Japan for those who want to practice, test their skills, and share experiences with each other. EASA (2017) indicated that promoting the drone education programs can raise safety awareness and operational skills among the public.

In addition to the measures for the operators, there are also some suggestions for drones and prohibited area. EASA (2017b) pointed out the need of the electric fences, the protection of the prohibited area, lighting and signal devices, and emergency landing devices for drones. China is the only country requiring the installation of an "electric fence" that stops drones from entering specific prohibited areas. China also requires drones to be connected to a "UAS Cloud," which has an alarm function that is activated when flights cross the electric fence. The frequency of reporting by operators depends on their weight and ability to operate within a designated area beyond VLOS (Du & Heldeweg, 2017).

ICAO (2018) suggested that keeping official statistics on types of drones

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activities, like incident and accident rates, will help decision makers develop informed policies that impact the regulated community. An accident report system coupled with a non-punitive, de-identified incident reporting system is essential to assessing the effectiveness of the regulation.

2. Privacy

The use of drones for military and civil applications has attracted a lot of attention to their ethical problems that they might infringe privacy and civil liberties (Kreps & Kaag, 2012). Some people even describe drones as a technology of ‘‘new surveillance’’, alongside closed circuit television and DNA techniques (Marx, 2004). Questions have been raised about whether it is ethically acceptable to monitor people from the air without their knowledge, and at what point this might become an unacceptable infringement of privacy or other human rights, such as freedom of association (Luo et al., 2014).

Drones also have privacy and other ethical implications when used for research. If people or their practices are identifiable from research data, should the people involved be asked for their consent to be surveyed from the air? What might be done with the data, and could there be negative repercussions for the people involved? For example, if data on farming practices collected by a drone reveal illegal forest clearance, will the data be passed on to a law enforcement agency, and might that result in harm to the person on the ground? Such questions are standard in the ethical protocols used by universities and other research agencies for research activities involving interviews or participant observation, which aim to ensure that research does no harm to respondents. To cope with this issue, FAA (2018) has included privacy guidance on its UAS registration website and in its mobile app. Such practice can also be applied in Taiwan.

3. Psychological well-being

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Drones could provide benefits for local people if they were available to be used for community-based forest monitoring to provide carbon measurements and various other useful data. In this sense, drones in the hands of local people could be socially empowering (Paneque-Galvez et al., 2014).

On the other hand, drones have the potential to cause considerable fear, confusion, and hostility among those on the ground. In some cases, this might happen as an accidental consequence of drones being introduced. If people on the ground do not understand, or refuse to believe, why drones are being introduced, they may generate conspiracy theories, suspicions and fantasies, particularly when they are used in remote areas in developing countries which have little prior exposure to electronic devices.

The likelihood that drones cause fear or alarm among those on the ground may be influenced by their material characteristics. Fixed wing devices are often very quiet and fly at several hundred metres altitude, meaning that they may not be noticed from the ground at all. They are also superficially similar in appearance to traditional piloted fixed wing aircraft. By contrast, rotary wing devices tend to be noisy, fly at low altitude and look nothing like previous aircraft, apart from a superficial similarity to helicopters. It seems likely that fixed wing drones will be less obtrusive and more easily acceptable to those on the ground, whereas rotary wing drones will be noticed and might cause alarm to those not expecting to see them. Drones might also negatively affect relations with local people where they replace face-to-face interactions with conservation workers. For example, a ranger on patrol can have a friendly conversation with a passerby, whereas this will not be possible if the patrol is carried out by a drone. Drones may also carry out different conservation actions than would have been the case if the operator were physically present on the ground because of the psychological effect of “distancing” (Sparrow, 2009).

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4. Data security

Some people may concern about how data collected by conservation drones are used and to what ends. Data collected by a law enforcement agency to prevent illegal hunting may be acceptable, but does this still apply if those same data are then sold on to a commercial entity such as an advertiser? Data may also be shared with wider networks such as state security agencies, which have been under attack from those concerned about civil liberties following recent revelations about their activities. Finally, hackers might steal data from drones, which are considered particularly susceptible to this problem as they can be shot down, collected and dismantled by those wishing to get access to data (Hartmann & Steup, 2013).

Drones can record a wide range of data. For example, drones equipped with cameras can capture images of persons, intentionally or unintentionally, which can provide information about different aspects of people's privacy, including their location, behavior, body characteristics and those with whom they associate alongside their loss of control over their image.

The specific privacy, data protection, and ethical issues associated with the civil use of drones are difficult to pin down, given drones' diverse capabilities and applications. For example, factors such as the purposes for which they are used, the extent and type of (personal) information that may be captured by the drone, the type of operator, the context and location of the drone operation, as well as the type of technology they carry all need to be considered when mapping potential privacy, data protection, and ethical impacts.

5. Environmental Interference

Environmental inference would not be the major concern in the use of drones, mainly because most drones are powered by electrical engines. Main environmental interferences are noise nuisance, especially the noise caused by small drones flying

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over residential areas (European Commission, 2015). The buzz sound in drones could amount to noise emission if a drone with a big engine flies at a low altitude above buildings. Another potential environmental pollution concerns the imprecise injection of particles, in particular pesticides, in agricultural use of drones.

6. Economic Issues

Economic concerns relate to both positive and negative aspects. The positive refer to the increased market of designing and producing drones as well as the business of providing professional operator services. For instance, it has been predicted that, once the civilian use of drones is integrated into civil aviation market, the growing drone activities will create a substantial number of jobs and economic benefit (MarketsandMarkets, 2015). The negative aspects encompass two dimensions, which are direct economic loss due to the crashes or the loss of expensive drones.

2.2 Strategies Regarding Drone Management

Some countries have highly restrictive regulatory regimes, some have "light touch" regulatory regimes that are far less prescriptive or constraining, and some have very limited existing law or policy that affects drones and their operation and use. This section provides drone management in different countries.

The regulatory framework around drone management issues is still developing. Many national and regional governments are focused on managing the safety issues associated with the integration of drones into civil air space.

2.2.1 Drone management strategies

The issues that drones bring indeed pose a threat to the public. Measures should be taken as soon as possible. However, rush attempts to regulate the technology may cause the intense public backlash. Therefore, some researchers studied the drone management strategies to help the public promote the policies smoothly.

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Altawy & Youssef (2017) suggested that drone manufacturers should include a list of no-fly GPS coordinates that cover sensitive areas such as airports, stadiums, and government facilities. New entries to this no-fly list should be included in the drone's mandatory firmware. Besides, the surveillance system should be implemented if necessary.

Brown & Jarrell (2016) indicated that the government should delegate to cities and local communities the management of near-ground, small drone operations. It could be achieved by the implementation of a locally operated, ground-based traffic management system. Moreover, ground-based navigation technologies are critical to an operational UAS urban grid. This would require the installation of specialized wireless technology on city streetlights, traffic lights, and similar elevated structures throughout the navigable space.

Stöcker et al. (2017) reviewed 19 states of drone regulations through literature review and the comparative analysis, and concluded that the main harms from drones are malfunction, mid-air collisions, and consequent damages to people and property on the ground. To address these harms, it was found that drones regulations focus upon three key aspects: (1) targeting the regulated use of airspace by UAVs; (2) imposing operational limitations; and (3) tackling the administrative procedures of flight permissions, pilot licenses and data collection authorization.

Nakamura & Kajikawa (2018) focused on the current discourse on drone safety regulations in Japan, and extended the System-theoretic Accident Model and Process (STAMP) approach to assess the regulations. Nakamura & Kajikawa conclude five issues for drones: (1) from prescriptive to performance-based regulation; (2) clarification of manufacturers responsibility and guidance of a safe design; (3) needing for specific requirements for pilots and operators; (4) technology development stimulation; and (5) safety enforcement and other issues.

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Finn & Wright (2016) conducted a survey in which there were European drone industry representatives, regulators and civil society organizations to examine privacy, data protection and ethics with respect to civil drone operations. Finn & Wright also indicated that although many responsible professional operators exist, there are significant gaps in the industry's knowledge about their privacy, data protection and ethical obligations under European and national laws. Therefore, Finn & Wright encouraged the interaction between drone organizations and educational mechanisms for drone operators.

Many studies have discussed drone management strategies through literature review. However, few of them confirmed the validity of these strategies conducted in their countries. Whether the strategies are suitable for the country should be further evaluated.

2.2.2 Drone management in Taiwan

In Taiwan, the national competent authority is the civil aeronautics administration. After the incident that a drone hit Taipei 101 hit the headlines, the complementary measures and the amendment of the enabling statute had been undertaking to manage drone activities. On April 3, 2018, the Legislative Yuan passed the amendment to the civil aviation act. The amendment added the chapter 9-2 "DRONE" to govern the use of drones. The president promulgated it on April 25, 2018 and it is due to take effect on 1 July, 2019. Since then, the amendment of other regulations related to drones has been in progress. However, because of the difficulty of the execution, the CAA announces the postpone of the date to 2020. In the chapter 9-2, drone management can be divided into 4 aspect: equipment and personnel management, activity areas, operation rules, and penalties. Table 2-1 shows more details of the 4 aspects.

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Table 2-1 The structure of drone management in the civil aviation act.

Aspect	Contents
Equipment and personnel management	● Registration of drone shall be required for the drone with maximum takeoff weight exceeding 250g. ● The operator of certain drones shall only operate the drone after passing the examination and being issued the operator certificate. ● Drone Inspection Certificate shall be issued.
Activity areas	● Central and local government management division ● Altitude above 400 ft, prohibited areas, and restricted areas shall be governed by the CAA. ● Except the area mentioned above, the altitude below 400 ft shall be governed by the local government.
Operation rules	● Operation of drone flight activities shall comply with the 10 rules, including flight altitude, operation time, operation range, and so on. ● Government agencies (institutions), schools or legal persons may apply to CAA with relevant documents for approval for exemption of restrictions.
Penalties	● Depend on the circumstances, there may be the penalty for violations. ● Where necessary, CAA may confiscate drones. ● Central and local government may be notified to enforce punitive procedures in conjunction with the police agency.

Source: CAA (2018).

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2.2.3 Drone management in the United States

The USA's air safety regulatory agency is the Federal Aviation Administration (FAA). Regulations for drone use in the US are split in different ways. First, there are three categories of drone use: commercial, model aircraft, and military. The FAA is charged with regulating who can fly drones, pilot requirements, drone registration, and what airspace a drone is authorized to use for the two civilian groups (that is, commercial and model aircraft). The military tends to govern itself regarding the use of drones.

The FAA publishes Federal Aviation Regulations (FARs), building on ICAO's SARPs. Most FAA regulations that will be relevant are found within Title 14 of the Code of Federal Regulations (CFR), Part 107 - SMALL UNMANNED AIRCRAFT SYSTEMS. This set of regulations are specific for drones and introduces a new FAA-issued Remote Pilot Certificate for the operation of drones.

Regulations regarding the registration of drones are found within 14 CFR 48. For UA above 55 lbs (total take-off weight) must be registered under the regulations described in 14 CFR 47. Under 14 CFR 48, drones must be registered with individual registration numbers, while Model Aircraft may be registered as a group under the owner of the Model Aircraft.

The use of Model Aircraft is regulated under 14 CFR 101 - MOORED BALLOONS, KITES, AMATEUR ROCKETS, UNMANNED FREE BALLOONS, AND CERTAIN MODEL AIRCRAFT. The definition of Model Aircraft is defined in Section 336 of Public Law 112-95. UA and UAS activity that does not meet the definition of Model Aircraft is by default, considered civil UAS activity and is subject to FAA regulations, such as 14 CFR 107 and 14 CFR 48.

The FAA regulations for commercial use do not differ very much from model aircraft use. Some of the most noteworthy differences are related to the pilot

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requirements and the operating rules. There is no pilot requirement for model aircraft use. However, to fly a drone for commercial purposes, a Remote Pilot Airman Certificate and Transportation Security Administration (TSA) vetting are required, and there is an age restriction (16). This certificate requires proficiency in the English language and the passing of an aeronautical skills test. The certificate expires after two years, at which point the pilot must take a refresher course to renew the certificate. A summary of the regulations for commercial and model aircraft use can be found in Table 2-2.

Table 2-2 FAA civilian drone regulations

	Commercial	Model aircraft
Pilot requirements	● Must have passed TSA vetting ● Must have a Remote Pilot ● Airman Certificate ● Must be over the age of 16	None
UAV requirements	● Must be under 55 lbs, or be registered if over 0.55 lbs ● Must undergo preflight check	Must be under 55 lbs, or be registered if over 0.55 lbs
Location	G airspace	Five miles from an airport (without prior authorization)
Operating rules	UAV must: - Yield to any manned aircraft - Stay within line of sight - Fly under 400 feet - Fly at less or equal to 100 mph - Not fly over people - Not fly from moving vehicle	UAV must: - Yield to any manned aircraft - Stay within line of sight - Follow community-based safety guidelines

Source: FAA (2018b).

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Rather than establishing a convenient online registration mechanism with virtually no beneficial effect, FAA could have instead imposed onerous conditions, thereby creating a strong incentive for drone operators to join a club and bring themselves within an environment that makes information available, and brings with it both a sense of responsibility and insurance coverage.

As a result, the FAA (2018b) is committed to an "education first" approach to integrating this growing community of unmanned aircraft users, which has included dedicated outreach and public service campaigns, trade show and conference participation, and collaboration with industry partners to ensure the safety message reaches the user community.

Faced with a growing community of new airspace users, the FAA (2018b) partnered with several leading industry groups to establish *Know Before You Fly*, an educational campaign to inform drone users about how to fly safely and responsibly. This campaign has been well received by most industry partners, and numerous drone manufacturers now voluntarily include *Know Before You Fly* educational materials in the packaging of their products.

Moreover, to increase situational awareness for this burgeoning community, the FAA (2018b) has developed a mobile application called B4UFLY. This application is aimed at helping recreational drone operators and model aircraft users know whether there are any restrictions or requirements in effect at the location where they want to fly using their phone's location services. The FAA released a full Apple version to the general public in January 2016, and a full Android version in March 2016.

Key features of the B4UFLY mobile application include:

- A clear "status" indicator that immediately informs operators about their current or planned location
- Information on the parameters that drive the status indicator

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- A "Planner Mode" for future flights in different locations
- Informative, interactive maps with filtering options
- Links to other FAA UAS resources and regulatory information

2.2.4 Drone management in Europe Union

The EU does not regulate drones whose mass is 150 kg or less, because the current governing regulation, Regulation 216/2008 on Common Rules in the Field of Civil Aviation, only covers aircraft whose mass is above that size. Such large drones fall within the competence of the EASA. Drones whose mass is less than 150 kg may be regulated at the Member State level.

Indeed, several Member States, including Austria, the Czech Republic, Denmark, Germany, France, Italy, Poland, Spain, and Sweden, have already adopted national rules. Because of differing national rules on criteria and conditions for the operation of drones and related safety issues, operators must apply for a separate authorization in each EU Member State.

On request by the European Commission, Member States and other stakeholders, the EASA adopted a document titled *Concept of Operations for Drones: A Risk Based Approach to Regulation of Unmanned Aircraft*, which urged regulation of the operation of drones in a manner proportionate to the risk of the specific operation, and also proposed to establish three categories of drone operations—Open, Specific, and Certified—with associated regulatory regimes. To mitigate privacy concerns, the EASA suggested the installation of chips/SIM cards in drones. Other suggestions included the self-registration of drone operations in a Web-based application maintained by the local authorities.

At the request of the Commission, the EASA on December 18, 2015, issued a Technical Opinion on Introduction of a Regulatory Framework for the Operation of Unmanned Aircraft. The Opinion contains twenty-seven specific proposals for a

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regulatory framework and for low-risk operations of all unmanned aircraft irrespective of their size. The Technical Opinion divides drones into three categories depending on risk:

1. **Open category (low risk):**

   Considering the risks involved, safety is ensured through operational limitations, compliance with industry standards, requirements on certain functionalities, and a minimum set of operational rules. Operations require neither an authorization by the competent authority nor a declaration by the UAS operator before the operation takes place. Enforcement shall be ensured by the police.

2. **Specific category (medium risk):**

   Considering the risks involved, do require an authorization by the competent authority, such as National Aviation Authorities (NAAs), before the operation takes place and take into account the mitigation measures identified in an operational risk assessment possibly assisted by a Qualified Entity (QE), except for certain standard scenarios for which a declaration by the UAS operator is sufficient. A manual of operations shall list the risk mitigation measures.

3. **Certified category (higher risk):**

   Considering the risks involved, requirements comparable to manned aviation requirements. It is required the issue of licenses and approval of maintenance, operations, training, Air Traffic Management (ATM)/Air Navigation Services (ANS) and aerodrome organizations by NAAs, and the design and approval of foreign organizations by EASA.

Based on the market’s needs, priority has been given to the development of a regulation for operations in “open” and “specific” category. The development of the

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regulation framework for operations in "certified" category is planned for 2018 and 2019.

The EU and its Member States have also adopted strict privacy and personal data rules, contained in the 1995 Data Protection Directive and based on articles 7 and 8 of the binding 2009 Charter of Fundamental Rights of the European Union, and on article 16 of the Treaty on the Functioning of the European Union. EU Members are also bound by article 8 of the Council of Europe Convention on Human Rights. In addition, Members have their own constitutional and statutory rules on privacy, and domestic legislation implementing EU legislation.

2.2.5 Drone management in Japan

There were no regulations explicitly mentioning drones in Japan, even by early 2015. At that time, many companies expressed their concerns that the absence of proper regulations might result in dangerous operations and accidents. If dangerous operations and accidents frequently happen, the governments and society will refuse drones business. Due to such concerns, many companies have refrained from full-scale investment on drone applications. It was unclear when and even which government agencies would regulate drone activities at that time. On 22nd April 2015, however, when a drone was found on the roof of the official residence of the Prime Minister Shinzo Abe, the environment surrounding drones changed drastically. The drone operator was indicted and received a suspended sentence of two years' imprisonment for the criminal act of forcible obstruction of business. On 24th April, Shinzo Abe and his cabinet held the first drones conference among related government agencies and started discussions to regulate drones. The amendment was promulgated on September 11, 2015, and became effective on December 10, 2015. As a result, the first drones-related regulation was initiated by the Japan Civil Aviation Bureau (JCAB).

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Under the amendment, a UAV operator is prohibited from flying a UAV, absent permission from the Ministry of Land, Infrastructure and Transportation (MLIT), in the following areas:

- Where air traffic is expected, such as airports and their approach areas, and areas above 150 meters
- Densely populated residential areas

The amendment also sets the conditions for UAV flights:

- UAV flights may be made only between dawn and dusk.
- An operator must monitor the UAV and its surroundings with his/her own eyes at all times.
- In-flight UAVs must keep more than 30 meters' distance from people and objects.
- UAVs must not fly over a place where an event attended by many people is being held.
- UAVs must not carry specified dangerous items, such as explosives and flammable objects.
- UAVs must not drop items while in flight.

These conditions may not apply in emergency situations or when an operator obtains prior approval from the MLIT. A UAV that weighs 200 grams or less is not subject to the rules in the Aviation Act.

The MLIT has requested that UAV operators report accidents, collisions, UAV falls, and near-miss incidents. Eleven cases were reported between the enforcement date of the amendment to the Aviation Act and March 30, 2016. Additional cases were reported to the police instead of the MLIT. Flying a UAV over a prohibited area or violating the conditions of flight is punishable by a fine of up to 500,000 yen (approximately US$4,000).

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The Act on Prohibition of Flying UAVs over Important Facilities and Their Peripheries was promulgated on March 18, 2016, and becomes effective three months from the date of promulgation. The Act prohibits flying UAVs over designated facilities, such as the Diet building, the Prime Minister's office building, buildings of designated government agencies that are involved in crisis management, the Supreme Court building, the Imperial Palace, embassies, and nuclear facilities. These no-fly areas generally extend to within a 300-meter radius of such designated facilities. Flying a UAV over a designated area is punishable by up to one year of imprisonment or a fine of up to 500,000 yen.

When a police officer finds a person flying a UAV over a designated area, the police officer can order the person to stop the operation of the UAV. If the person does not follow the order, the police officer can take necessary measures, such as obstructing the flight of and destroying the UAV in order to remove any danger it poses. In addition, the person who did not follow the officer's order is punishable by up to one year of imprisonment or a fine of up to 500,000 yen.

2.2.6 Drone management in China

China has not passed any legislation specifically regulating drones. However, China's civil flight regulatory agency, the Civil Aviation Administration of China (CAAC), has issued advisory circulars setting up guidelines for the flight of UAS since 2015.

On December 29, 2015, the CAAC issued the Interim Provisions on Light and Small Unmanned Aircraft Operations (UAS Operation Provisions), which provide the basic regulation on categories, pilots, electric fence and UAS cloud, prohibited areas, flight specifications, insurance, and manufacturing and sale.

In order to strengthen the management of civil unmanned aircraft systems, CAAC developed the Regulations contained herein on the real-name registration of

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civil UAS owners. Starting August 31, 2017, civil UAS owners must make real-name registrations through the UAS real-name registration system.

Moreover, the CAAC issued Provisions on the Administration of Operators in the Civilian Unmanned Aircraft System in 2013, and revised it in 2016 and 2018. The Provisions divide UAS and unmanned airships subject to its regulation into seven categories, mainly based on weight and use, as follows:

Table 2-3 Categories of UAV in China

Category	Empty weight	Maximum takeoff weight
I	0 kg<W≦0.25 kg	
II	0.25 kg<W≦4 kg	1.5 kg<W≦7 kg
III	4 kg<W≦15 kg	7 kg<W≦25 kg
IV	15 kg<W≦116 kg	25 kg<W≦150 kg
V	Plant protection UAS	
VI	Unmanned airships	
VII	Category I and II UAS that can operate 100 meters beyond visual line of sight.	
XI	116 kg<W≦5,700 kg	150 kg<W≦5,700 kg
XII	W>5,700 kg	

Source: CAAC (2018).

The UAS Operation Provisions set forth an online, real-time supervision system comprising the "electric fence," a system consisting of hardware and software that stops aircraft from entering certain areas, and the "UAS Cloud," a dynamic database management system that monitors flight data, such as operation information, location, altitude, and speed, in real time, which has an alarm function for UAS connected to it that is activated when these UAS fly into the electric fence. Airport obstacle control surfaces, as well "prohibited areas, restricted areas, and danger zones" provided by

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other laws and regulations, are prohibited areas prescribed by the UAS Operation Provisions. UAS connected to the UAS Cloud must follow the restrictions shown in the system, while those not connected to the UAS Cloud must consult with relevant authorities about the prohibited areas. Operators must report at least every second when in densely populated areas and at least every thirty seconds when in non-densely populated areas.

To cope with the situations of illegal operations of drone, in China the local public security bureau ever offered the award for information about drones flying near to the transport hub.

2.3 Summary

The potential benefits from the use of drones have been demonstrated in a variety of civil applications including crop and infrastructure management, emergency management, search, and rescue, law enforcement, environmental research, and many other applications often described as being too dull, dirty, dangerous, or demanding for conventionally piloted aircraft (CPA). However, as well as benefits, the operation of drones has associated risks. To mitigate the concerns raised among the public, not only has literature provided suggestions, but also each country has conducted some measures. Most literature indicated the suggested strategies through literature review. However, these strategies should be verified in case the cultural conflict causes the difficulty of implementation. In accordance with the management strategies mentioned in the literature, this research summarizes these strategies with the 3E principle and the policy aspect in Table 2-4. These strategies will be further discussed by experts in Taiwan.

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Table 2-4 Safety management strategies of drones

Aspect	Strategy	Source
Policy and Regulation	Expand the range of liability insurance objects	Yen (2016), Chen (2015), Du & Heldeweg (2017), Levush (2016)
	Establish the drone operation and training associations	FAA (2018b), EASA (2018) , Finn & Wright (2016)
	Establish the drone arenas	Du & Heldeweg (2017)
	Perform risk management and set performance targets	ICAO (2018), EASA (2017b), Du & Heldeweg (2017)
Education and Promotion	Promote the drone education programs	EASA (2017b), Levush (2016)
	Dedicate safety outreach with experts	FAA (2018b)
	Set up the drone APP	Stöcker et al. (2017), FAA (2018b), EASA (2017b)
	Set warnings notices of drones in the prohibited areas	EASA (2017b), Levush (2016)
Engineering and Technology	Set the electric fences	EASA (2017b), Du & Heldeweg (2017), Levush (2016)
	Strengthen the protection of the prohibited areas	FAA (2018b), Shelley (2018), EASA (2017b)
	Install lighting and signal devices	ICAO (2015), EASA (2017b), Levush (2016)
	Install emergency landing devices	Stöcker et al. (2017), EASA (2017b)
Enforcement and Surveillance	Strengthen inspection manpower	EC (2015)
	Strengthen reporting mechanism	Baraniuk (2017), Levush (2016)
	Prepare the jamming equipment	Shelley (2018), Levush (2016)
	Implement the drone operation tracking system	Yen (2016), Du & Heldeweg (2017), Levush (2016)

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Chapter 3 Research Design and Methodology

In this research, the framework of drone management strategies is established through literature review. Next, experts will be invited to examine the framework via the first-stage questionnaire. The second-stage questionnaire will be formulated and the FAHP and IAA method will be used to assess the relative importance and achievability. With the weighting value obtained from the FAHP and IAA method, the ZOGP will be conducted to evaluate the resource allocation in different scenarios.

3.1 Fuzzy Analytic Hierarchy Process (FAHP)

3.1.1 Analytic Hierarchy Process (AHP)

The analytic hierarchy process (AHP) method was first purposed by Saaty in 1971 to solve resource allocation problem in military. Through the AHP method, decision maker can deconstruct a complex problem to a simple hierarchy, which can provide the information to support decision maker choosing an appropriate option, and reducing the risk of making a wrong decision (Saaty, 1980). The primary advantage of AHP approach is simple, easy, and can effectively capture the opinion of experts and decision makers (Zahedi et al., 1986).

The procedures of the AHP method involve six essential steps (Saaty, 1980).

Step 1: Define the unstructured problem and state clearly the objectives and outcomes.

Step 2: Decompose the complex problem into a hierarchical structure with decision elements.

Step 3: Employ pairwise comparisons among decision elements and form comparison matrices.

Step 4: Use the eigenvalue method to estimate the relative weights of the

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decision elements.

Step 5: Check the consistency property of matrices to ensure that the judgments of decision makers are consistent.

Step 6: Aggregate the relative eights of decision elements to obtain an overall rating for the alternatives.

3.1.2 Evaluation steps

Despite of the wide applications, the conventional AHP method is often criticized due to its use of unbalanced scale of judgments and its inability to adequately handle the inherent uncertainty and imprecision in the pair-wise comparison process. Decision-makers usually face difficulty to consider the relative importance of one criterion or alternative in terms of another when facing complex and uncertain problems. Therefore, to overcome this problem, the fuzzy analytic hierarchy process was proposed.

Several FAHP methods have been proposed by various authors. The first method was proposed by Van Laarhoven & Pedrycz (1983). In that method, elements in the reciprocal matrix were expressed by triangular fuzzy numbers. Chang (1996) used triangular fuzzy numbers for the pairwise comparison scale of FAHP and extent analysis for the synthetic extent values of pairwise comparisons. The essential steps of FAHP are summarized as follows (Chang, 1992; Javanbarg et al., 2012; Lee & Seo, 2016):

Step 1: Establishing the hierarchical structure:

Construct the hierarchical structure with decision elements, decision-makers are requested to make pair-wise comparisons between decision alternatives and criteria using a nine-point scale. All matrices are developed, and all pair-wises comparisons are obtained from each n decision-maker.

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Table 3-1 Standardized comparison scale of nine levels

Definition	**Value**
Equal importance	1
Weak importance	3
Essential importance	5
Demonstrated importance	7
Extreme importance	9
Intermediate values	2, 4, 6, 8

Step 2: Calculating the consistency:

To ensure that the priority of elements is consistent, the maximum eigenvector or relative weights and λ_{max} are calculated. Then the consistency index (CI) for each matrix order *n* is computed in Eq. (3.1). Based on CI and random index (RI), the consistency ratio (CR) is calculated. The CI and CR are defined as follows (Saaty, 1980):

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3.1}$$

$$CR = CI/RI \tag{3.2}$$

where n is the number of items being compared in the matrix, λ_{max} is the largest eigenvalue, and *R.I.* is a random consistency index obtained from a large number of simulation runs, and it varies upon the order of the matrix (Table 3-2).

Table 3-2 Random index (RI)

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

Source: Saaty (1980).

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Step 3: Sum up each row of fuzzy judgment matrix to get the fuzzy number vector RS.

$$\mathrm{RS} = \begin{bmatrix} rs_1 \\ rs_2 \\ \vdots \\ rs_n \end{bmatrix} = \begin{bmatrix} \sum_{j=1}^{n} \tilde{a}_{1j} \\ \sum_{j=1}^{n} \tilde{a}_{2j} \\ \vdots \\ \sum_{j=1}^{n} \tilde{a}_{nj} \end{bmatrix} = \begin{bmatrix} \sum_{j=1}^{n} l_{1j} & \sum_{j=1}^{n} m_{1j} & \sum_{j=1}^{n} u_{1j} \\ \sum_{j=1}^{n} l_{2j} & \sum_{j=1}^{n} m_{2j} & \sum_{j=1}^{n} u_{2j} \\ \vdots & \vdots & \vdots \\ \sum_{j=1}^{n} l_{nj} & \sum_{j=1}^{n} m_{nj} & \sum_{j=1}^{n} u_{nj} \end{bmatrix} \quad (3.3)$$

where $\tilde{a}_{nj} = (l_{nj},\ m_{nj},\ u_{nj})$ with l_{nj} is the lower, u_{nj} is the upper limit, and m_{nj} is the geometric mean of l_{nj} and u_{nj}.

Step 4: Normalize the row fuzzy number vector RS to get the fuzzy synthetic extent value vector S.

$$\tilde{S} = \begin{bmatrix} \tilde{s_1} \\ \tilde{s_2} \\ \vdots \\ \tilde{s_n} \end{bmatrix} = \begin{bmatrix} rs_1 \otimes \left(\sum_{j=1}^{n} rs_j\right)^{-1} \\ rs_2 \otimes \left(\sum_{j=1}^{n} rs_j\right)^{-1} \\ \vdots \\ rs_n \otimes \left(\sum_{j=1}^{n} rs_j\right)^{-1} \end{bmatrix} \quad (3.4)$$

where $\left(\sum_{j=1}^{n} rs_j\right)^{-1}$ is the derivative of the sum of the fuzzy number vector RS and it is calculated by Eq. (3.5).

$$\left(\sum_{j=1}^{n} rs_j\right)^{-1} = \left(\frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} u_{kj}},\ \frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}},\ \frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} l_{kj}}\right) \quad (3.5)$$

Step 5: Compute the degree of possibility to get the non-fuzzy weight vector V.

$$\mathrm{V} = \mathrm{RS} = \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \end{bmatrix} = \begin{bmatrix} minV(\tilde{s_1} \geq \tilde{s_k}) \\ minV(\tilde{s_2} \geq \tilde{s_k}) \\ \vdots \\ minV(\tilde{s_n} \geq \tilde{s_k}) \end{bmatrix} \quad (3.6)$$

where for element i, the subscript $k \in \{1, 2, \ldots, n\}$ and $k \neq i$. Also the degree of possibility of $\tilde{s_2} = (l_2, m_2, u_2) \geq \tilde{s_1} = (l_1, m_1, u_1)$ is obtained by Eq. (3.7)

$$V(\tilde{s_2} \geq \tilde{s_1}) = \begin{cases} 1, & if\ m_2 \geq m_1 \\ 0, & if\ l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \quad (3.7)$$

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Step 6: Define the final non-fuzzy normalization weight vector W.

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} v_1/\sum_{i=1}^{n} v_i \\ v_2/\sum_{i=1}^{n} v_i \\ \vdots \\ v_n/\sum_{i=1}^{n} v_i \end{bmatrix} \tag{3.8}$$

3.2 Importance-Achievability Analysis (IAA)

Chang & Wong (2012) combined relative importance obtained from the AHP approach and achievability assessment scores to classified into high and low levels in the management map. Such method will be applied in this research and illustrated as following:

Step 1: Obtain the fuzzy weight vectors through the FAHP method.

Step 2: Evaluate the achievability scores by 5-scale linguistic variables. In other words, the achievability level will be measured by using “very low”, “low”, “medium”, “high”, and “very high” to represent the scores of “0–20”, “20–40”, “40–60”, “60–80”, and “80–100”, respectively.

Step 3: Transfer the 5-scale linguistic variables into triangular fuzzy numbers and defuzzy them. For example:

$d_{krt}, t = 1, 2, \ldots, m$ represents the linguistic membership function of *k* assessment items under *r* criterion given by the expert; the triangular fuzzy number of *k* assessment items in the *r* linguistic membership function is as follows:

$$A_{krt} = (L_{krt}, M_{krt}, U_{krt}) \tag{3.9}$$

where $L_{krt} = \min\{d_{kr1}, d_{kr2}, \ldots, d_{krm}\}$

$$M_{krt} = \sqrt[m]{\prod_{t=1}^{m} d_{krt}}$$

$$U_{krt} = \max\{d_{kr1}, d_{kr2}, \ldots, d_{krm}\}$$

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Defuzzification using the centroid method, proposed by Teng & Tzeng (1993), to change a fuzzy value into a nonfuzzy value:

$$DF_i = [(UR_i - LR_i) + (MR_i - LR_i)]/3 + LR_i,\ \forall i \qquad (3.10)$$

Step4: Establish the management map in which the vertical axis of the grid represents the relative importance of the strategy and the horizontal axis indicates the achievability score. As Figure 3-1 shows. Martilla & James (1977) suggested that median values as a measure of central tendency are theoretically preferable to means because a true interval scale may not exist. However, means can be acceptable when the outcome of using mediums does not perform well.

In this research, all strategies are placed into one of the four quadrants to provide the government an important reference when considering drone management strategies.

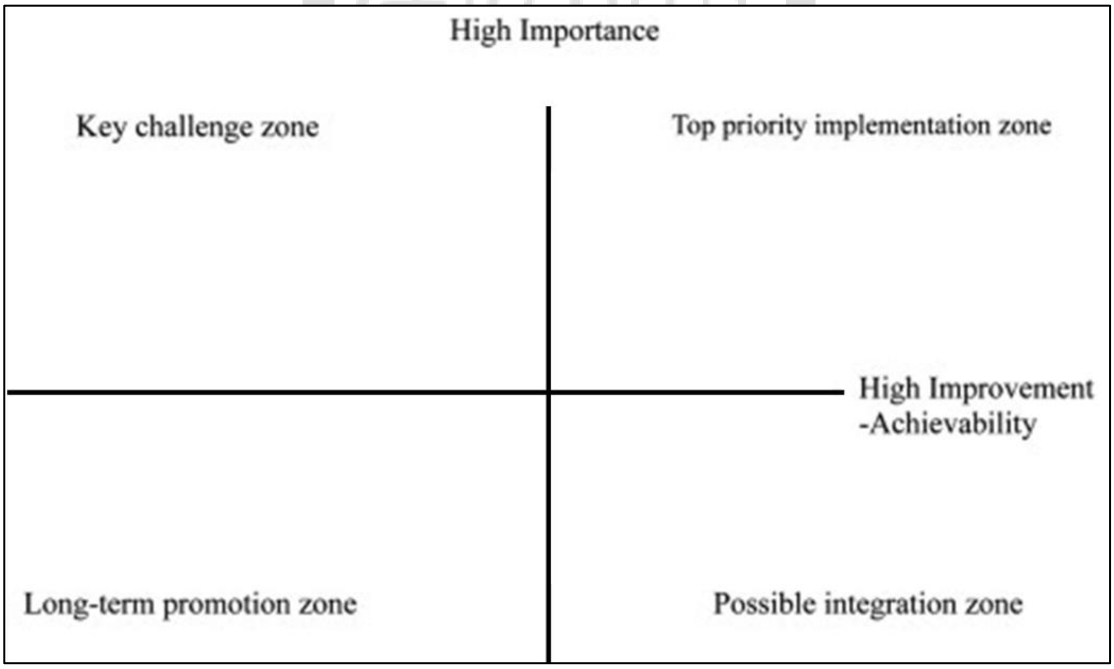

Figure 3-1 Importance-Achievability management map

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3.3 Zero-One Goal Programming (ZOGP)

Due to the allocation of budgets, manpower, and time, the strategies with high importance and achievability may be difficult to execute. Therefore, this research further uses the zero-one goal programming (ZOGP) model to reduce the errors in the assessment and make the results of the research more realistic. Moreover, compared with other methods, the ZOGP model will not lead to more complicated intermediate models, and thus will have lower computational requirement. More importantly, the ZOGP model espouses the philosophy of satisficing, which corresponds to human decision making. In fact, human tends to select satisfactory alternatives instead of optimal alternatives (March & Simon, 1958).

The ZOGP model is a popular technique in the multiple criteria decision making (MCDM) model, and has been widely adopted in many real-world problems.

The goal programming (GP) was first introduced by Charnes, Cooper, & Ferguson in 1955, but the actual name first appeared in "Management models and industrial applications of linear programming" in 1961 (Charnes & Cooper, 1957). The methodology has been applied in a variety of situations involving multiple and conflicting decision making. It has also further developed various models, such as lexicographic GP (LGP), MINMAX GP (MGP), weighted GP (WGP), mixed binary GP (MBGP), and ZOGP (Liao, 2009).

Among these models, ZOGP can assign optimal values for planning process and managerial policy in resources distribution. Santhanam, Muralidhar, & Schniederjans (1989) also stated the ZOGP has the following advantage:

1. Integrating multiple and conflicting goals.
2. Comparing goals with incommensurable units.
3. Prioritizing goals in line with organizational objectives.
4. Considering and measuring intangible benefits.

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5. Considering resource constraints explicitly.

6. Selecting the optimal set of projects that has the maximum benefits with the constraints of resources.

The ZOGP model is described as follows (Tripathy & Biswal, 2007):

$$Minimze\ Z = \{g_1(d_1^-, d_1^+), g_2(d_2^-, d_2^+), \ldots, g_m(d_m^-, d_m^+)\} \quad (3.11)$$

Subject to

$$\sum_{j=1}^{n} c_{ij}X_j + d_i^- - d_i^+ = b_i \quad for\ i = 1, 2, \ldots, m \quad (3.12)$$

$$X_j = 0, 1 \quad for\ j = 1, 2, \ldots, n \quad (3.13)$$

where m = the number of goals to be considered in the model, n = the number of alternative strategies to be considered in the model, i = 1st, 2nd, …, mth goal, j = 1st, 2nd, …, mth strategy, g_m = the priority of each goal for the organization, $d_m^{\pm}$ = the positive and negative deviation, c_{ij} = the jth strategy usage parameter of the ith goal, b_i = the ith available resource or limitation factors that must be considered in the selection decision, and X_j = a zero-one variable.

The objective function is to minimize the sum of the prioritized positive and negative deviation, d_m^+ and d_m^-. If the positive deviation is included in the objective function, the model will attempt to minimize the amount by which the goals exceeded. On the other hand, the model will attempt to minimize the amount by which the goals are underachieved if the negative deviation is included in the objective function. Moreover, if both positive and negative deviations are included in the objective function, the model will attempt to equal the amount which the goals are set. To avoid the situation that both underachieved and exceeded goals exist, the product of negative deviation and positive deviation should be 0.

We define the decision variable as X_j, where $j = 1, 2, \ldots, n$, corresponding to

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the n projects available for selection. $X_j = 1$ if project j is selected and 0 otherwise. g_i represents the priority of each goal for the organization. In this research, we set the goals as the same priority. These goals can be divided into two categories: tangible goals or intangible goals. Owing to the nature of the projects, certain goals cannot be quantified such as, organization learning, decision making effectiveness, improving planning etc. In such situations, each benefit type can be scored or ranked and then include in the ZOGP model. In this research, we use the product of the relative importance value and the achievability values to prioritize the strategies.

3.4 Summary

This research uses the above three methods, including the fuzzy analytic hierarchy process, importance-achievability analysis, and the zero-one goal programming method, to evaluate the importance and achievability of the strategies, and to allocate resources in different scenarios. The combination of FAHP and IAA has been generally applied in evaluating policies (Chang, Yeh, & Wang, 2007). Since the evaluation of drone safety management strategies is a new issue in Taiwan, it is necessary to evaluate not only the importance of the strategies but also the achievability of the strategies. In this research, the drone management strategies are firstly developed, and the proposed strategies are screened by experts. The formulated questionnaire is used to screen out the overall management strategies of the research, and the fuzzy analytic hierarchy process and importance-achievability analysis are used. To make this research more practical, the zero-one goal programming is further applied in this research. Such method has been widely used in many studies. It offers a systematic, easy-to-use approach to the strategy selection decision problem. For example, Schniederjans & Wilson (1991) used the method to the information system project selection problem. After calculating the importance and achievability value of

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each strategy to obtain the weighting value of each drone management strategy, the weighting values are substituted into the zero-one goal programming and the implemented strategies selected in each simulation scenario will be obtained. This research combines FAHP, IAA, and ZOGP as a novel approach to solve the strategy selection decision problem.

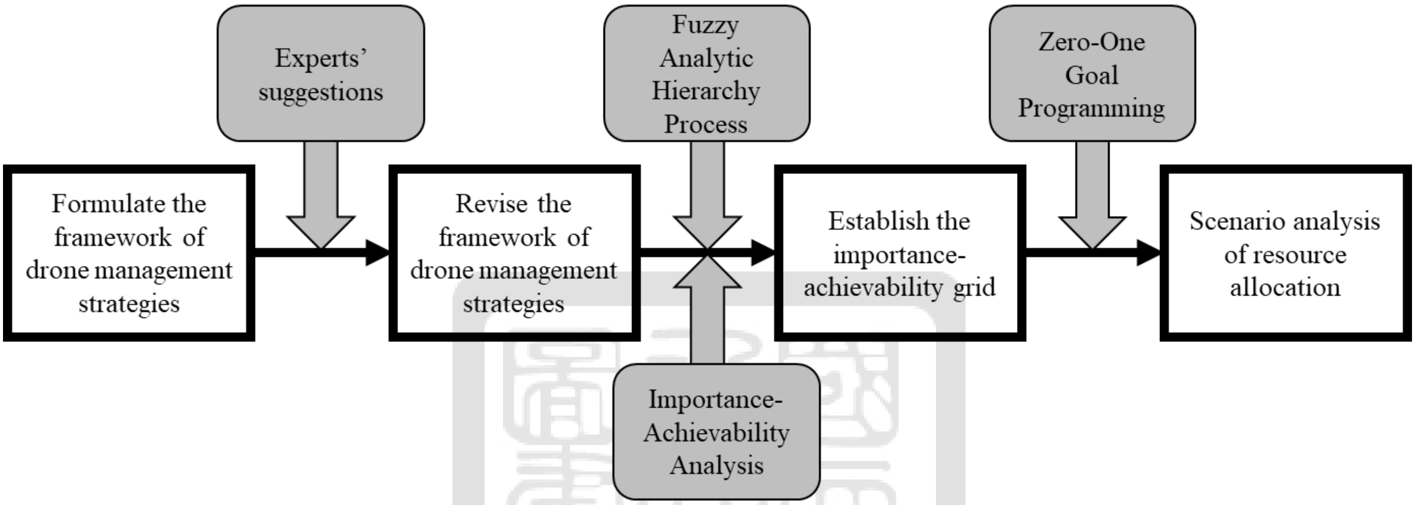

Figure 3-2 Application process of research methodology

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Chapter 4 Empirical Analysis

It is important for the government to prioritize the drone management strategies to ensure the effective implementation. In this research, we evaluated and prioritized drone management strategies based on the viewpoints of industry, government, and academic experts. With the zero-one goal programming, the reasonable resource allocations in different scenarios are provided. This is indeed a new contribution to drone management in Taiwan. The outcome of this research will also help other countries gain a strategic understanding of drone management and implement their own management strategies.

4.1 Content Validity

4.1.1 Development of Drone Management Strategies

The framework of drone management strategies is formulated regarding to the literature review. To improve safety, 3E principle has been widely used and provided a useful framework. The experience of successful countries shows that success can only be achieved through integrated action, e.g. by following the 3E rule (Education, Enforcement, Engineering). As a result, based on the 3E principle (Education, Engineering, and Enforcement) and policy, the drone management strategies are divided into 4 dimensions and 16 strategies. The goal of these strategies is to improve safety and reliability level of drones. The drone safety is the desired optimum state where drone operations executed in certain circumstances can be controlled within an acceptable operational risk (Wackwitz & Boedecker, 2015). With regard to the incidents of runway incursion and damage to people or property, this research aims to improve safety and reliability level of drones to decrease the drone incidents and control the operational risk. These aspects and strategies will be examined by experts

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including government officials, scholars, and drone development association to confirm the appropriateness of the concepts and strategies further.

1. Policy and Regulation

According to literature review, regulation and policy is emphasized in every drone management strategy. The range of liability insurance includes the recreational drone pilots in some countries, but still not in Taiwan. Moreover, the establishment of the drone operation and training associations can achieve efficient management. Furthermore, the establishment the drone arenas can help the operators enhance their skills. Last, performing risk management and setting performance targets can evaluate the efficiency of implementation practices. The strategies and the definitions of drone management are presented as

Table 4-1.

Table 4-1 Strategies and definitions of policy and regulation

	Strategy	Definition
1	Expand the range of liability insurance objects	Currently, only the government agencies, schools, or legal persons are required to purchase liability insurance. However, the techniques of the recreational drone pilots may not as good as the commercial drone pilots. The risk is nonnegligible, so the recreational drone pilots shall also purchase liability insurance.
2	Establish the drone operation and training associations	Encourage to establish the drone operation and training association to educate members of the public and increase awareness of correct safety operation.
3	Establish the drone arenas	Establish the drone arena for those who want to practice, test their skills, and share experiences with each other.
4	Perform risk management and set	Record all kind of incidents related to drones, and even set the safety performance target for continuous reviews and

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	performance targets	improvements.

2. Education and Promotion

The FAA has dedicated the “Education First” policy. The promotion of the drone education programs can cultivate correct awareness and nurture talents among the young groups. Also, the safety outreach with experts can ensure the safety message reaches the user community Besides, there are some measures to strengthen drone safety propaganda in other countries, such as setting up the drone app. It is also suggested that the warnings notices of drones should be set in the prohibited areas. The strategies and definitions of education and promotion are condensed as Table 4-2.

Table 4-2 Strategies and definitions of education and promotion

	Strategy	**Definition**
1	Promote the drone education programs	Collaborate with high schools or universities to promote the drone education program to provide safety awareness, operational skills, and concepts of the drone regulations.
2	Dedicate safety outreach with experts	Dedicate outreach and public service campaigns, trade show and conference participation, and collaboration with industry partners to ensure the safety message reaches the user community.
3	Set up the drone APP	Set up the drone APP, helping operators and know whether there are any restrictions or requirements in effect at the location where they want to fly using their phone’s location services and the drone regulations.
4	Set warnings notices of drones in prohibited areas	Warnings and infringement notices shall be set up in the boundary of the prohibited areas.

3. Engineering and Technology

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The engineering and technology aspect can be seen as the last line of defense against drone incidents. The electric fences are widely used in China. In Certain airports in the UK, the anti-UAV defense system is used to detect drones. The lighting and signal devices and emergency landing devices are also suggested to be installed in drones. The strategies and definitions of engineering and technology are sorted out as Table 4-3

Table 4-3 Strategies and definitions of engineering and technology

	Strategy	Definition
1	Set the electric fences	Set the electric fence, a system consisting of hardware and software that stops aircraft from entering certain areas, around the airport or other prohibited areas.
2	Strengthen the protection of the prohibited areas	Set up the anti-UAV defense system, can detect, track, identify, and defeat a drone in approximately 15 seconds at a range of up to 6 miles, around the airport or other prohibited areas.
3	Install lighting and signal devices	Lighting and signal device, such as anti-collision lighting, shall be installed to be identified easily or issue an alert in the case of malfunction.
4	Install emergency landing devices	Device about the failure and safety instruments like parachutes that can safely terminate the flight in emergency situations shall be installed.

4. Enforcement and Surveillance

The last aspect is regarding the enforcement level. The strengthening of inspection manpower can help alleviate the burden of existing manpower. In China, rewards are used to strengthen the reporting mechanism. The jamming equipment and the drone operation tracking system can also significantly improve the enforcement efficiency. The strategies and definitions of enforcement and surveillance are

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summed up as Table 4-4.

Table 4-4 Strategies and definitions of enforcement and surveillance

	Strategy	Definition
1	Strengthen inspection manpower	Related authorities can intensify publicity and patrol regularly in the prohibited areas.
2	Strengthen reporting the mechanism	Offer rewards to the public for reporting the information about any unauthorized use of drones.
3	Prepare the jamming equipment	Purchase the jamming equipment, such as drone guns and capturing net, to disrupt or disable drones, and enhance enforcement efficiency.
4	Implement the drone operation tracking system	Set up the tracking management systems to collect flight data of drones, and provide proper improvement.

All the dimensions and the strategies are concluded in Figure 4-1.

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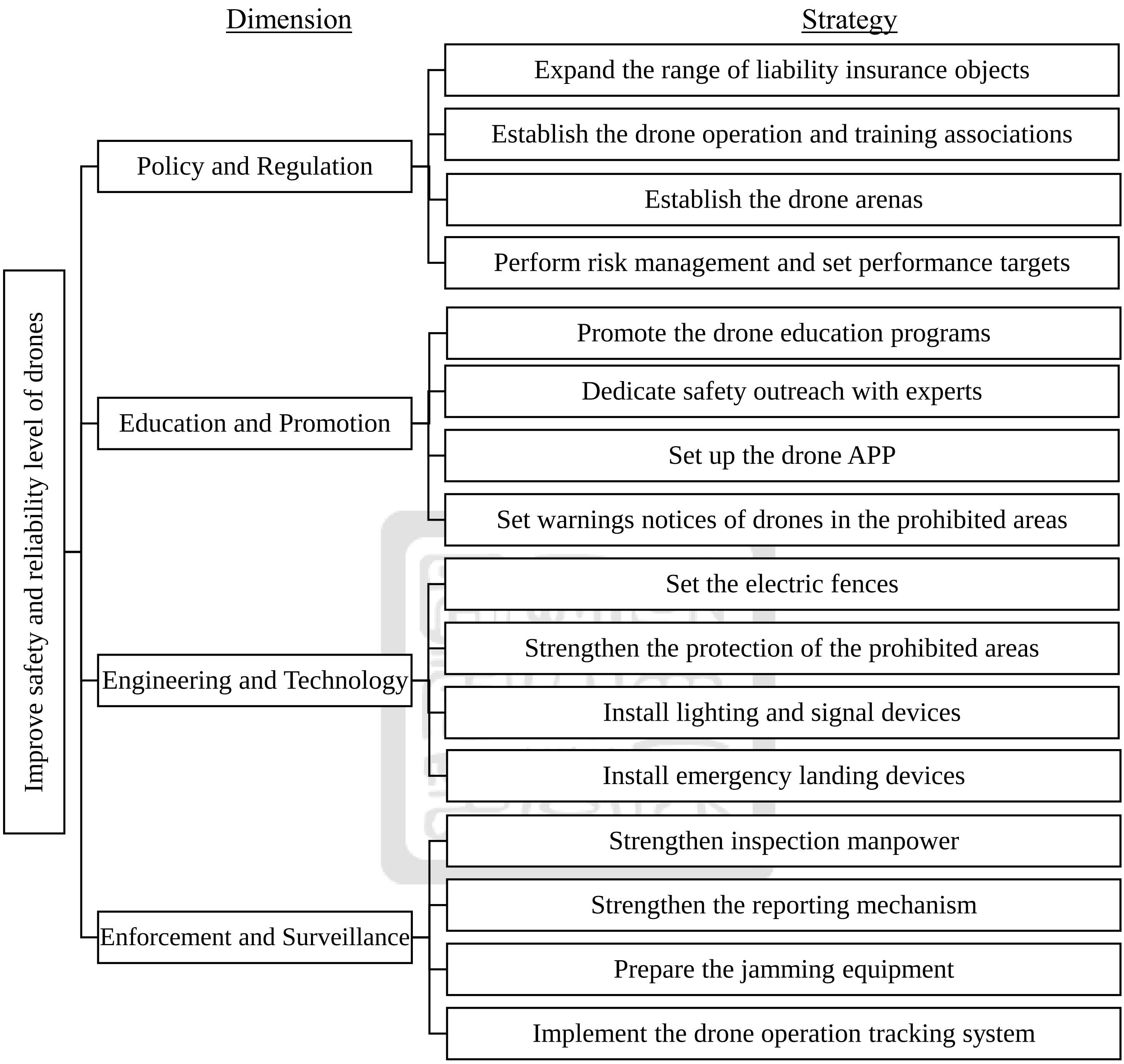

Figure 4-1 Framework of drone management strategies

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4.1.2 Revision of Drone Management Strategies

After the first-stage questionnaire, this research revises the framework of drone safety management strategies with the suggestions from experts. First, four pillars of aviation safety management systems suggested in the ICAO's Annex 19 are served as the new dimension of the strategies. A safety management system is a systematic approach to managing safety, including organizational structures, accountabilities, policies, and procedures. An SMS is scalable so it can be tailored to the size and complexity of each organization. It indeed has been applied in many studies, company, and even countries. When using 3E policies, some strategies could not be classified adequately. As a result, experts agree to replace SMS with 3E1P.

Some strategies are removed from the framework because of the inappropriateness. For example, the experts suggested that compared to other strategies, expanding the range of liability object does not fit in the framework. Setting the electric fences, strengthen the protection of the prohibited areas, and strengthening inspection manpower are combined into the new strategy, which is strengthening safety inspection mechanism in prohibited areas. Gearing regulations to international conventions is included as a new strategy. Because the drone management around the world is still immature, the regulations and measures still keep refining and differ from country to country. After integrating the suggestions from 6 experts, the revised framework of drone management strategies is shown as Table 4-5 and Figure 4-2.

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Table 4-5 Strategies and definitions of the revised drone management strategies

Dimension	Strategy	Definition
Safety policy and objectives	Set safety performance targets	Record all kind of incidents related to drones, include the data into CAA's aviation safety statistic data, and even set safety performance targets for follow-up reviews and improvements.
	Gear regulations to the international conventions	In response to environmental changes, continuously review the drone regulations to gear regulations to the international conventions and legislate for legal operators.
	Assign testing and certificating authorities	Assign current drone associations or establish the drone operation & training association to supervise operators, establish correct drone safety concepts, and provide testing and certificating services.
	Integrate drone information system	Integrate and make full use of existing resources, such as prohibited areas, prohibited areas, regulations, and weather information, through information system. Present information through APPs, websites, and so on, to help operators plan, apply, or set navigation before flights.
Safety risk management	Strengthen law enforcement personnel's ability of hazard identification and evaluation	Arrange education training program and provide the law enforcement guidance by the CAA or assigned organization to strengthen law enforcement personnel's ability of hazard identification and evaluation.
	Strengthen safety inspection mechanism in prohibited areas	Strengthen safety inspection mechanism in prohibited areas by improving hardware and software, such as setting up automated-detection devices, installing electricity fences, replenishing manpower, and so on.
	Implement crash-avoidance technology	To prevent damage on personnel and property when drones lose power or malfunction, drones with certain weight or operating in certain area should install emergency landing devices, such as parachutes that can safely terminate the flight mission.

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Table 4-5 Strategies and definitions of the revised drone management strategies (Continued)

Dimension	Strategy	Definition
Safety assurance	Implement the drone operation tracking system	Set up the tracking management systems to collect flight data of drones immediately or afterward to ensure the understanding on drone usage and provide proper improvement.
	Increase efficiency of violation enforcement	Increase efficiency of violation enforcement in prohibited areas, such as purchasing drone guns, capturing nets, and other jamming equipment, to disrupt or disable drones.
	Develop reporting procedures or regulations	To avoid misreporting, the CAA should require manufactures to provide educational materials in the packaging of their products, and provide guidelines on websites. For example, FAA provide reporting guidance to ensure the integrity of the reporting procedure.
Safety promotion & education	Construct drone safety culture	Dedicate touring propaganda to local communities in collaboration with experts, or provide drone associations with subsides to conduct touring propaganda, so as to construct drone safety culture among the general public.
	Continuously improve operators' skills	Provide channels for the public to practice or train anytime. For instance, establish the drone arena for those who want to practice, test their skills, and share experiences with each other.
	Promote drone education programs	Promote the awareness and skill of flight safety, and make the public understand the related regulations by means of collaborating with high schools or universities to promote the drone education or vocational training programs to provide safety awareness, operational skills, and concepts of the drone regulations.

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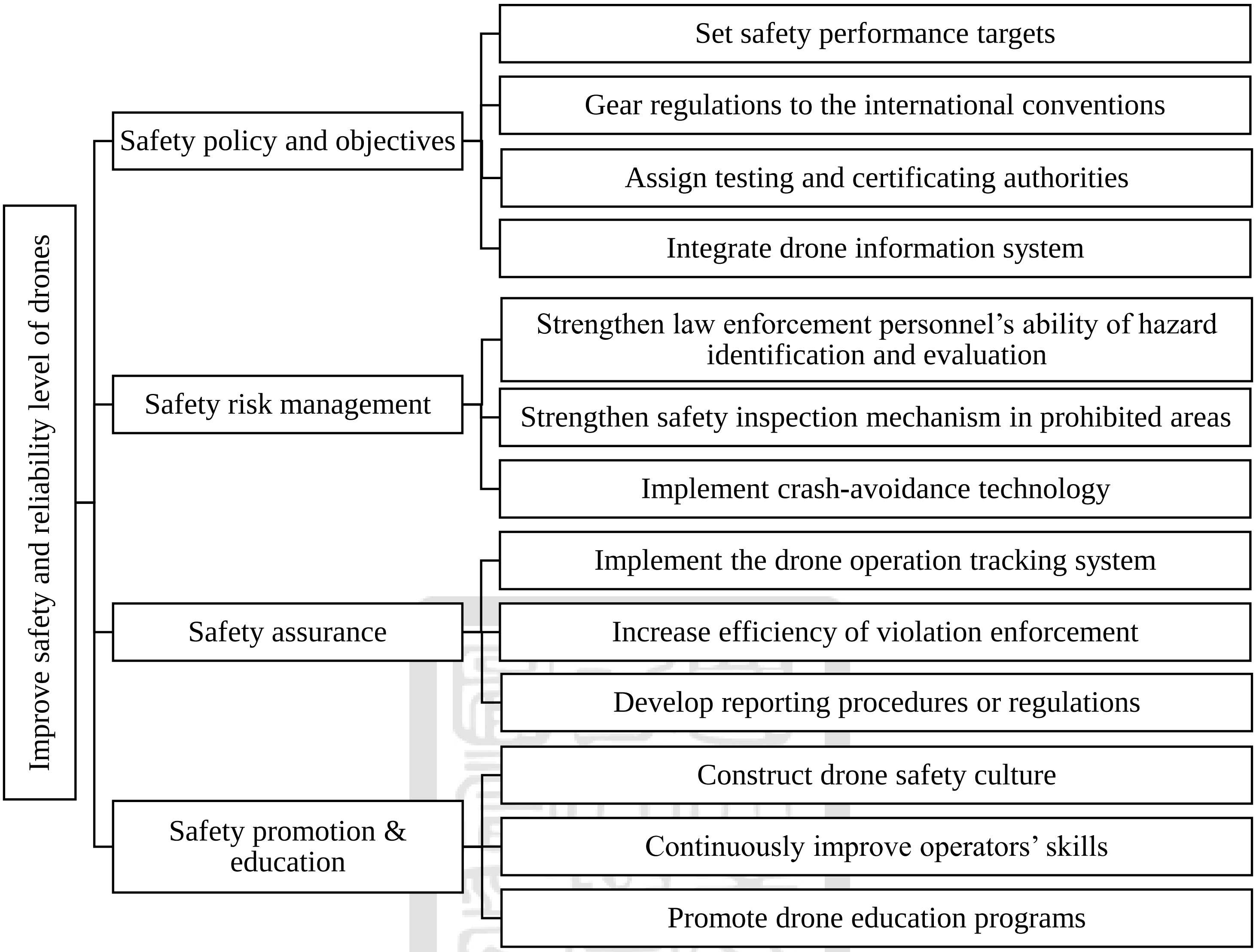

Figure 4-2 Revised framework of drone management strategies

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4.2 Measurement of Importance Value

The second-stage questionnaire of this research is formulated based on the framework of drone management strategies mentioned in chapter 4.1. In particular, this questionnaire will be distributed to Taiwanese experts, so the Chinese questionnaire will be provided. The questionnaire in Chinese is presented in Appendix A.

During January and February 2018, 19 questionnaires were distributed, and 13 effective responses were received, involving 4 experienced experts from drone associations, 4 governmental officials, and 5 academic researchers in the field of aviation. Table 4-6 shows the results of the questionnaire response, and Table 4-7 provides the background information of the responded experts.

Table 4-6 Results of questionnaire response

	Sent out	**Return**	**Rate of Response (%)**	**Questionnaire With CR<0.2**	**Rate of Effectiveness (%)**
Industry	5	4	80	4	100
Government	8	4	50	4	100
Academia	6	6	100	5	83.3

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Table 4-7 Experts background information

Attribute	Institution/ Company	Characteristics	No. of valid QNR
Industry	Miaoli UAS Innovation and Development Association	Experienced experts in drone associations which are in response to drone management and development issues.	4
	Miaoli UAS Innovation and Development Association		
	Chinese Society of Photogrammetry & Remote Sensing		
	Taiwan UAS Development Association		
Government	Civil Aeronautics Administration	Governmental officials in the Civil Aeronautics Administration or airports with more than 10-year experience.	4
	Civil Aeronautics Administration		
	Kaohsiung International Airport		
	Taipei Songshan Airport		
Academia	National Yunlin University of Science & Technology	Professors in the field of transportation science.	5
	National Kaohsiung First University of Science and Technology		
	Chang Jung Christian University		
	Chang Jung Christian University		
	Feng Chia University		
	Asia University, Taiwan		

The consistency ratio (CR) should be less than 0.1 in order to ensure that the matrix is reliable (Saaty, 2001). However, Bodin and Gass (2003) indicated that in practice it would be difficult to completely fit the rule, CR$\leqq$0.1. Therefore, it is

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acceptable to use the questionnaire with CR slightly larger than 0.1. In this research, CR=0.2 is regarded as the threshold value. After examining the 13 questionnaire forms collected, the consistency ratio of one questionnaire was found to be higher than 0.2. Therefore, this questionnaire forms were deemed to be invalid (Table 4-8).

Table 4-8 Consistency ratio of the experts

No.	**Aspect**	**Safety policy and objectives (P)**	**Safety risk management (R)**	**Safety assurance (A)**	**Safety promotion & education (E)**
1	0.125	0.178	0.030	0.090	0.074
2	0.059	0.144	0.069	0.003	0.170
3	0.080	0.195	0.117	0.033	0.000
4	0.125	0.029	0.033	0.016	0.158
5	0.065	0.043	0.000	0.000	0.000
6	0.063	0.027	0.033	0.033	0.033
7	0.022	0.018	0.081	0.000	0.006
8	0.080	0.053	0.000	0.008	0.016
9	0.150	0.011	0.117	0.187	0.056
10	0.063	0.027	0.033	0.033	0.033
11	0.165	0.104	0.117	0.141	0.117
12	**0.277**	0.057	**0.254**	0.000	0.000
13	0.077	0.000	0.000	0.069	0.016
14	0. 050	0. 044	0. 028	0. 066	0. 000

Table 4-9 shows the relative importance of dimensions evaluated from the 13 experts. “Safety policy and objectives” is the top-ranking dimension, while safety assurance is the bottom-ranking dimension among all experts. As for safety risk

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management and safety promotion & education, the experts from the industry give safety promotion & education higher rank than safety risk management, which is different from the rank provided from the experts from the government and academia.

Table 4-9 Group fuzzy weight vectors

Aspect	Industry		Government		Academia		Overall	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Safety policy and objectives (P)	0.400	1	0.473	1	0.579	1	0.459	1
Safety risk management (R)	0.183	3	0.208	2	0.181	2	0.189	3
Safety assurance (A)	0.157	4	0.131	4	0.095	4	0.146	4
Safety promotion & education (E)	0.260	2	0.188	3	0.145	3	0.205	2

Table 4-10 shows the relative importance of the drone management strategies evaluated from the 13 experts. In terms of overall relative importance, "set safety performance targets" (P1), "gear regulations to the international conventions" (P2), "integrate drone information system" (P4), "assign testing and certificating authorities" (P3), and "assign testing and certificating authorities" (E3) are the 5 top-ranking drone management strategies. Since drone issues have become the talk of the town in these years, many regulations and coordinated sets of measures are still in execution and refining. As a result, the overall experts consider safety performance targets and regulation-refining the most important strategies. To quickly lead the public to understand the regulations, it is also important to assign the authorities and offer drone information from different channels.

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Table 4-10 Group ranking outcomes

Strategy	Industry		Government		Academia		Overall	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank
(P1) Set safety performance targets	0.131	1	0.170	1	0.262	1	0.154	1
(P2) Gear regulations to the international conventions	0.111	3	0.110	3	0.171	2	0.116	2
(P3) Assign testing and certificating authorities	0.095	5	0.072	6	0.062	6	0.081	4
(P4) Integrate drone information system	0.063	8	0.121	2	0.084	3	0.108	3
(R1) Strengthen law enforcement personnel's ability of hazard identification and evaluation	0.029	13	0.098	4	0.062	5	0.059	9
(R2) Strengthen safety inspection mechanism in prohibited areas	0.117	2	0.069	7	0.052	9	0.076	6
(R3) Implement crash-avoidance technology	0.037	12	0.041	11	0.067	4	0.055	10
(A1) Implement the drone operation tracking system	0.045	11	0.040	12	0.045	10	0.048	12
(A2) Increase efficiency of violation enforcement	0.057	9	0.058	8	0.037	12	0.054	11
(A3) Develop reporting procedures or regulations	0.054	10	0.033	13	0.014	13	0.044	13
(E1) Construct drone safety culture	0.074	7	0.057	9	0.054	7	0.063	8
(E2) Continuously improve operators' skills	0.083	6	0.046	10	0.053	8	0.064	7
(E3) Promote drone education programs	0.104	4	0.085	5	0.038	11	0.079	5

Experts in different fields have different viewpoints. Generally, governmental officials often take a pessimistic or conservative view, while academic experts tend to take an optimistic or progressive view. The industry involved basically takes a practical view, which is often between views held by the government and the

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academic. For the industry, strengthening safety inspection mechanism in prohibited areas is more important than gearing regulations to the international conventions. Instead of offering drone information to the public, preventions from incidents should be taken first. Moreover, the education on the public is more important than on the law enforcement personnel.

From the governmental officials' view, offering drone information to the public and educating the law enforcement personnel are more important than strengthening the inspection mechanism. Besides, it is more commended to promote education programs rather than offer places to allow operators to practice.

Experts from academia provide different views that crash-avoidance technology is very important when it comes to improving safety and reliability level of drones. Moreover, instead of passively promoting the education programs to wait the public, touring propaganda is more important and proactive.

4.3 Importance-Achievability Analysis

According to the part II of the second-questionnaire, this research combines the relative importance value with achievability value to analyze the difference between them. As Table 4-11 shows, the 5 top-ranking of achievability of strategies are "gear regulations to the international conventions" (P2), "develop reporting procedures or regulations" (A3), "assign testing and certificating authorities" (P3), "increase efficiency of violation enforcement" (A2), and "continuously improve operators' skills" (E2).

In the dimension of safety policy and objectives, "set safety performance targets" (P1) and "integrate drone information system" (P4) have high importance but low achievability. In fact, it is difficult for the police to track and catch the errant drones. On March 15, 2019, the Taipei Songshan airport was closed for a while because of

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the invasion of a drone. The police still haven't caught the perpetrators. From this case, it is obvious that the datum and reports of drone incidents are difficult to obtain. It leads to the low achievability to set safety performance targets. Since the amendment of the Civil Aviation Act, the CAA has integrated the drone information system for months. However, it is still on process because of the uncertainty of the supporting measures.

Basically, the strategies in the dimension of safety risk management are with low achievability. Because drones are too small to be captured, it is hard to efficiently strengthen the inspection mechanism in prohibited areas. The implementation of crash-avoidance technology may also cause public backlash for the cost of drones may increase.

In dimension of safety assurance, two of the strategies have high achievability. Actually, the FAA has offered reporting procedures on its website to ensure the completeness of the reporting process. The CAA has purchased drone guns to increase efficiency of violation enforcement in prohibited areas, but it is criticized that the number of drone guns is not enough to meet the need.

As for the dimension of the safety promotion and education, it is concluded that instead of touring propaganda, the education programs are more achievable. Because the time and other resources taken by touring propaganda are much more than education programs.

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Table 4-11 The value and rank of importance and achievability for each strategy

Strategy	Weight	Rank	Achievability	Rank
(P1) Set safety performance targets	0.154	1	72.70	7
(P2) Gear regulations to the international conventions	0.116	2	81.27	1
(P3) Assign testing and certificating authorities	0.081	4	78.59	3
(P4) Integrate drone information system	0.108	3	71.03	8
(R1) Strengthen law enforcement personnel's ability of hazard identification and evaluation	0.059	9	69.37	11
(R2) Strengthen safety inspection mechanism in prohibited areas	0.076	6	70.09	10
(R3) Implement crash-avoidance technology	0.055	10	59.80	13
(A1) Implement the drone operation tracking system	0.048	12	70.21	9
(A2) Increase efficiency of violation enforcement	0.054	11	78.16	4
(A3) Develop reporting procedures or regulations	0.044	13	79.16	2
(E1) Construct drone safety culture	0.063	8	61.94	12
(E2) Continuously improve operators' skills	0.064	7	77.50	5
(E3) Promote drone education programs	0.079	5	73.75	6

The strategies' relative importance and achievability scores are integrated and classified into relatively high and low categories using a measurement of central

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tendency (Figure 4-3). The vertical axis of the grid represents the relative importance of the management strategies from high to low, while the horizontal axis indicates the achievability from high to low. By coupling these two sets of scores, drone management strategies are divided into one of the four quadrants of the importance-achievability grid. Martilla & James (1977) suggested that median values as a measure of central tendency are theoretically preferable to means because a true interval scale may not exist. Based on the classification by relative importance and achievability, there are four kinds of management strategies at different levels of implementation.

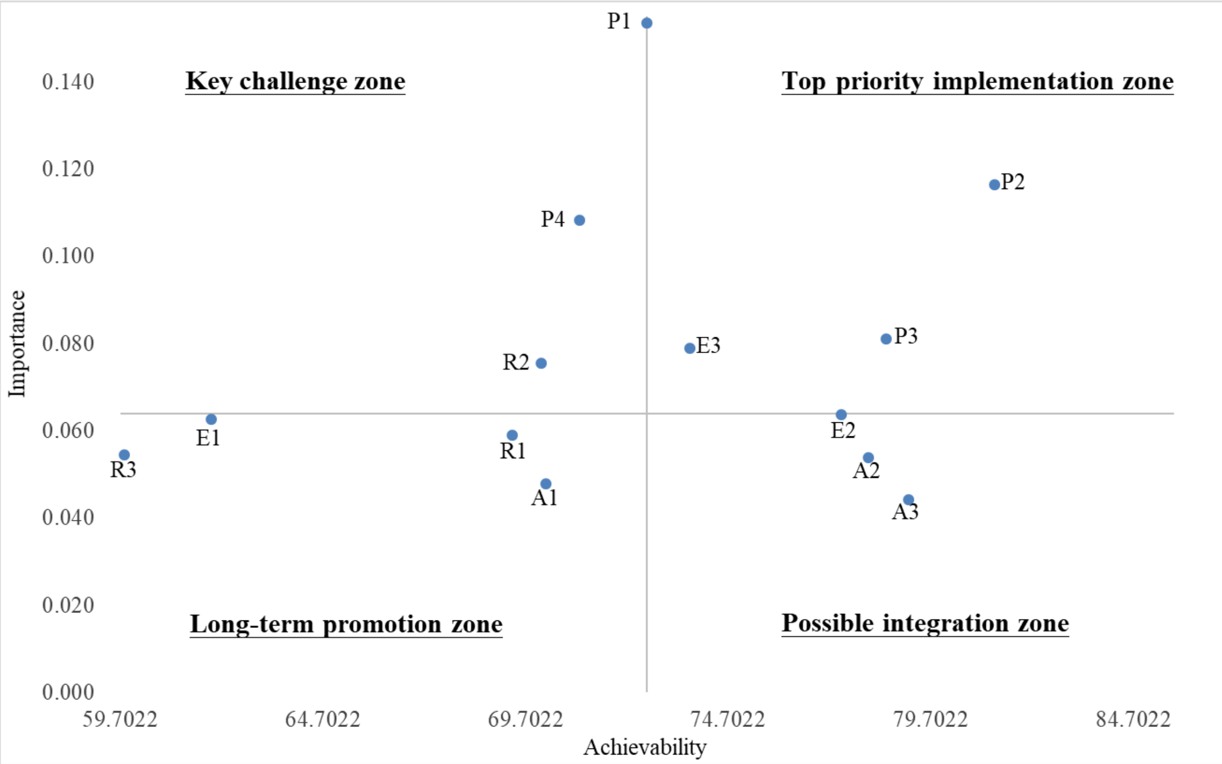

Figure 4-3 The relationships of the achievability and relative importance of drone management strategies

1. The top priority implementation zone

Strategies allocated in this zone are seen as highly important with the potential for achieving improvement, including “set safety performance targets” (P1), “gear regulations to the international conventions” (P2), “assign testing and certificating authorities” (P3), and “promote drone education programs” (E3).

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In this zone, three strategies are from the dimension of safety policy and objectives. It indicated that the government should make more effort on safety policy and objectives. In 2017, EASA issued annual safety review, and analyzed the key risk areas and set targets for improvement with occurrences collected by the European Member States. In Taiwan, the CAA issues the number of reported occurrences of releasing objects considered hazardous to flight safety around the airports. It is important for the government to provide the official statistics and further set the safety performance targets in order to systemically improve the drone safety management.

In Europe, the drone rules are subjected to a uniform level, and it is urged that the laws should be geared to the international standards and recommended practices. According to EASA (2017), most of the drone accidents are related to drone pilots losing control of the drone resulting in a damage and most often a destruction of the aircraft. This result directly emphasizes the importance of education programs which can help strengthen the skill and safety awareness of drone operators.

In Taiwan, the CAA planned to conduct the license pre-test for drone operators. The standard mechanism will be established afterward, and the testing and certificating authorities will be assigned in the future. Besides, drone education programs have already offered to students and the general public. For instance, the Chang Jung Christian university provides the bachelor degree program of applied unmanned aerial vehicle technology, while the labor affairs department of New Taipei City Government offers the vocational training of drones.

2. The possible integration zone

Strategies in the integration zone are referred to as having low importance, but high achievability. They include "increase efficiency of violation enforcement" (A2), "develop reporting procedures or regulations" (A3), and "continuously improve operators' skills" (E2).

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In Taiwan, the drone management measures are planned into two-step measures. First, the CAA will purchase more drone guns and install inspection device to increase efficiency of violation enforcement because of the achievability. In the US, reporting procedures or regulations have been published on the website. Although the effectiveness of this measure may not be so optimistic, it indeed provides a procedure for the public to comply with. In Asia, many countries, including China, Korea, and Japan, have establish arenas to improve the drone operators' skills and prosper the drone industry.

3. The key challenge zone

Strategies allocated to this zone are referred to as being highly important, but low achievability. There are two strategies, "integrate drone information system" (P4), and "strengthen safety inspection mechanism in prohibited areas" (R2), belonging this zone.

Drone operators are in need of up-to-date, accurate, and easily understandable information to identify the restrictions or requirements. As a result, it needs the cooperation between the government and the industry to make it accessible through a stand-alone portable application device, such as tablets, or smartphones. In fact, the CAA had published the development of the drone information system since the amendment of the Civil Aviation Act. However, because of the complex geographic information and unfamiliarity of the local government, the promotion of drone information system must be postponed to 2020.

Besides, according the second-stage questionnaire, experts agree that strengthening safety inspection mechanism in prohibited areas is highly important, especially the experts from the industry. The CAA even announced that the drone management measures are planned into two-step measures. In the second-step plan, all drones should install the electricity fences before 2026, which means the measure

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is important but needs time to be developed and accepted.

4. The long-term promotion zone

Strategies allocated here are of low importance and low achievability, and include “strengthen law enforcement personnel’s ability of hazard identification and evaluation” (R1), “implement crash-avoidance technology” (R3), “implement the drone operation tracking system” (A1), and “construct drone safety culture” (E1).

Because the drone management is still immature, some strategies may be regarded as the obstacles of the development of the industry. According the first-stage questionnaire, experts suggested that the crash-avoidance technology and drone operation tracking system are difficult to be implemented in Taiwan because of the complex specifications of drones and the cost of installation. Moreover, the drone management measures were originally planned to be carried out on July 1, 2019. However, due to the local governments’ unfamiliarity with the regulation, the measures are postponed to be executed on January 1, 2020. It shows the difficulty to strengthen the law enforcement personnel’s ability of hazard identification and construct drone safety culture in public.

4.4 Resource Allocation in drone management strategies

4.4.1 Formulation of zero-one goal programming

Although the expert questionnaire provides the relative importance and achievability of each strategy, the execution of each strategy may be influenced by time, manpower, or budget in practice. As a result, the ZOGP model is applied to display the resource allocation for each strategy in different scenarios. Table 4-12 shows the value of each strategy’s resource evaluation. Since the strategy, “gear regulations to the international conventions” (P2), is defined as continuously reviewing the drone regulations, it would be difficult to evaluate the value of the

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resources. That is, strategy P2 is removed from the ZOGP model.

The evaluation value of required time and manpower is based on the suggestion for the management level of the CAA, while the required budgets are according to the CAA Operating Fund annual budget report in 2019. For each strategy, the number of each strategy's budgets are almost the same as the similar strategy in the report.

Table 4-12 Values of each strategy's resource evaluation

Dimension	Strategy	Required time (month)	Required manpower (person)	Required budgets (NTD 10,000)
Safety policy and objectives (P)	(P1) Set safety performance targets	6	2	400
	(P3) Assign testing and certificating authorities	6	3	900
	(P4) Integrate drone information system	12	4	500
Safety risk management (R)	(R1) Strengthen law enforcement personnel's ability of hazard identification and evaluation	18	5	200
	(R2) Strengthen safety inspection mechanism in prohibited areas	36	6	800
	(R3) Implement crash-avoidance technology	36	5	600
Safety assurance (A)	(A1) Implement the drone operation tracking system	36	6	1,300
	(A2) Increase efficiency of violation enforcement	20	4	250
	(A3) Develop reporting procedures or regulations	6	4	100
Safety promotion & education (E)	(E1) Construct drone safety culture	18	9	250
	(E2) Continuously improve operators' skills	18	4	500
	(E3) Promote drone education programs	18	5	100

Note that these resource factors are not constraints. It is not even expected that all of them can be satisfied simultaneously. The goal column values are not fixed constants

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but are flexible managerial goals to be approached as closely as possible. Therefore, the objective of ZOGP is to minimize the deviation variables. In Table 4-13, all strategies can be conducted simultaneously within the certain period, A, which is based on the scenario. In all scenarios, all strategies can be carried out simultaneously. The total required manpower of strategies conducted should not be bigger than the value B, so do the required budgets. In the model, only time, manpower, and budgets are the only resources selected. However, other factors, such as cultures, environment, politic, may influence the outcome whether the strategies should be conducted. As a result, this research uses the product of the value of relative importance and achievability instead of the value of relative importance to represent the priority levels of each strategy. To prevent the resources from wasting, sum of the product of the value of relative importance and achievability should as bigger as possible.

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Table 4-13 ZOGP model formulation

ZOGP model formulation	**Goals**
Minimize $Z = P_1 d_1^+ + P_2 d_2^+ + P_3(d_3^- + d_3^+)$	Satisfying three resource constraints
Subject to	
$W_n^t X_n \le A$	Avoiding over-utilizing maximum time
$\sum_1^{12} W_n^m X_n + d_1^- - d_1^+ = B$	Avoiding over-utilizing maximum manpower
$\sum_1^{12} W_n^b X_n + d_2^- - d_2^+ = C$	Avoiding over-utilizing maximum budgets
$\sum_1^{12} W_n^i W_n^a X_n + d_3^- - d_3^+ = \sum_1^{12} W_n^i W_n^a$	Selecting all strategies with the maximum product of relative importance and achievability value
$X_n = 0 \; or \; 1, for \; n = 1,2,\ldots,12$	
where P = the priority of each goal for the CAA, d = the deviation variable, W_n^t = the required time of the n^th^ strategy, A = the maximum conducted time for the CAA, W_n^m = the required manpower of the n^th^ strategy, B = the maximum total manpower of the CAA, W_n^b = the required budget of the n^th^ strategy, C = the maximum total budget of the CAA, W_n^i = the importance value of the n^th^ strategy, and W_n^a = the achievability value of the n^th^ strategy.	

4.4.2 Scenario Analysis of resource allocation

Based on the evaluated resources and the model formulation, the results of the 4 scenarios are computed by the LINDO 6.1 software.

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Scenario 1: Resources are limited.

Assume that the CAA wants to improve the safety and reliability levels of drones in Taiwan in 18 months. The estimated amount of manpower is 20, and the total budget on drone management is NTD 20 million.

Table 4-14 Resource constraints in scenario 1

Resource	Constraint
Required time (month)	$W_n^t X_n \leq 18$
Required manpower (person)	$\sum_1^{12} W_n^m X_n + d_1^- - d_1^+ = 20$
Required budgets (NTD 10,000)	$\sum_1^{12} W_n^b X_n + d_2^- - d_2^+ = 2000$

The LINDO 6.1 software is used to solve the ZOGP model. The results are as follows:

$X_1 = X_2 = X_3 = X_9 = X_{12} = 1,$

$X_4 = X_5 = X_6 = X_7 = X_8 = X_{10} = X_{11} = 0,$

$d_1^- = 2, d_1^+ = 0, d_2^- = 0, d_2^+ = 0, d_3^- = 29.04749, d_3^+ = 0.$

Based on the results, these strategies should be selected when the resources are limited, including "set safety performance targets" (P1), "assign testing and certificating authorities" (P3), "integrate drone information system" (P4), "develop reporting procedures or regulations" (A3), and "promote drone education programs" (E3).

Scenario 2: Resources are abundant.

Assume that the CAA wants to improve the safety and reliability levels of drones in Taiwan in 36 months. The estimated amount of manpower is 40, and the total budget on drone management is NTD 40 million.

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Table 4-15 Resource constraints in scenario 2

Resource	Constraint
Required time (month)	$W_n^t X_n \leq 36$
Required manpower (person)	$\sum_1^{12} W_n^m X_n + d_1^- - d_1^+ = 40$
Required budgets (NTD 10,000)	$\sum_1^{12} W_n^b X_n + d_2^- - d_2^+ = 4000$

The LINDO 6.1 software is used to solve the ZOGP model. The results are as follows:

$X_1 = X_2 = X_3 = X_4 = X_5 = X_8 = X_9 = X_{11} = X_{12} = 1,$

$X_6 = X_7 = X_{10} = 0,$

$d_1^- = 3, d_1^+ = 0, d_2^- = 250, d_2^+ = 0, d_3^- = 10.50506\, , d_3^+ = 0.$

According to the results, these strategies should be selected when the resources are limited, including "set safety performance targets" (P1), "assign testing and certificating authorities" (P3), "integrate drone information system" (P4), "strengthen law enforcement personnel's ability of hazard identification and evaluation" (R1), "strengthen safety inspection mechanism in prohibited areas" (R2), "increase efficiency of violation enforcement" (A2), "develop reporting procedures or regulations" (A3), "continuously improve operators' skills" (E2), and "promote drone education programs" (E3).

Scenario 3: Choose the top nine important strategies when manpower is limited.

Assume that the CAA wants to improve the safety and reliability levels of drones in Taiwan in 36 months. The total budget on drone management is NTD 40 million, but the estimated amount of manpower is only 20. Therefore, the CAA needs to consider the top nine ranking strategies.

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Table 4-16 Resource constraints in scenario 3

Resource	Constraint
Required time (month)	$W_n^t X_n \leq 36$
Required manpower (person)	$\sum_{1}^{12} W_n^m X_n + d_1^- - d_1^+ = 20$
Required budgets (NTD 10,000)	$\sum_{1}^{12} W_n^b X_n + d_2^- - d_2^+ = 4000$
Choose the top nine important strategies	$X_6 = X_7 = X_9 = 0$

The LINDO 6.1 software is used to solve the ZOGP model. The results are as follows:

$X_1 = X_2 = X_3 = X_8 = X_{11} = X_{12} = 1,$

$X_4 = X_5 = X_6 = X_7 = X_9 = X_{10} = 0,$

$d_1^- = 0, d_1^+ = 2, d_2^- = 1350, d_2^+ = 0, d_3^- = 23.39843, d_3^+ = 0.$

Based on the results, these strategies should be selected when the resources are limited, including "set safety performance targets" (P1), "assign testing and certificating authorities" (P3), "integrate drone information system" (P4), "increase efficiency of violation enforcement" (A2), "continuously improve operators' skills" (E2), and "promote drone education programs" (E3).

<u>Scenario 4: Choose the top nine important strategies when resources are all limited.</u>

Assume that the CAA wants to improve the safety and reliability levels of drones in Taiwan in 18 months. The total budget on drone management is only NTD 20 million, and the estimated amount of manpower is 20. With limited resources, the CAA needs to consider the top nine ranking strategies.

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Table 4-17 Resource constraints in scenario 4

Resource	Constraint
Required time (month)	$W_n^t X_n \leq 18$
Required manpower (person)	$\sum_{1}^{12} W_n^m X_n + d_1^- - d_1^+ = 20$
Required budgets (NTD 10,000)	$\sum_{1}^{12} W_n^b X_n + d_2^- - d_2^+ = 2000$
Choose the top nine important strategies	$X_6 = X_7 = X_9 = 0$

The LINDO 6.1 software is used to solve the ZOGP model. The results are as follows:

$X_1 = X_3 = X_4 = X_{11} = X_{12} = 1,$

$X_2 = X_5 = X_6 = X_7 = X_8 = X_9 = X_{10} = 0,$

$d_1^- = 0, d_1^+ = 0, d_2^- = 300, d_2^+ = 0, d_3^- = 29.87674, d_3^+ = 0.$

Based on the results, these strategies should be selected when the resources are limited, including "set safety performance targets" (P1), "integrate drone information system" (P4), "strengthen law enforcement personnel's ability of hazard identification and evaluation" (R1), "continuously improve operators' skills" (E2), and "promote drone education programs" (E3).

4.5 Sensitivity Analysis

In this section, sensitivity analysis is conducted to predict the outcome of a decision given a certain range of variables. By creating a given set of variables, the CAA can determine how changes in one variable affect the outcome.

In Table 4-18, the current maximum manpower is 20 people, while the maximum budget is NTD 20 million in scenario 1. With sensitivity analysis, if the CAA insists conducting the strategies, P1, P2, P3, A3, and E3, the maximum manpower can

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decrease into 18 people, and the maximum budget cannot change.

Table 4-18 Ranges of RHS in different scenario

Scenario	Resource	Current RHS	Allowable increase	Allowable decrease	Range of RHS
1	Manpower (B)	20	Infinity	2	B ≥ 18
	Budget (C)	2,000	0	0	C=2000
2	Manpower (B)	40	Infinity	3	B ≥ 37
	Budget (C)	4,000	Infinity	250	C ≥ 3750
3	Manpower (B)	20	Infinity	2	B ≥ 18
	Budget (C)	4,000	Infinity	1350	C ≥ 2650
4	Manpower (B)	20	0	0	B=20
	Budget (C)	2,000	Infinity	300	C ≥ 1700

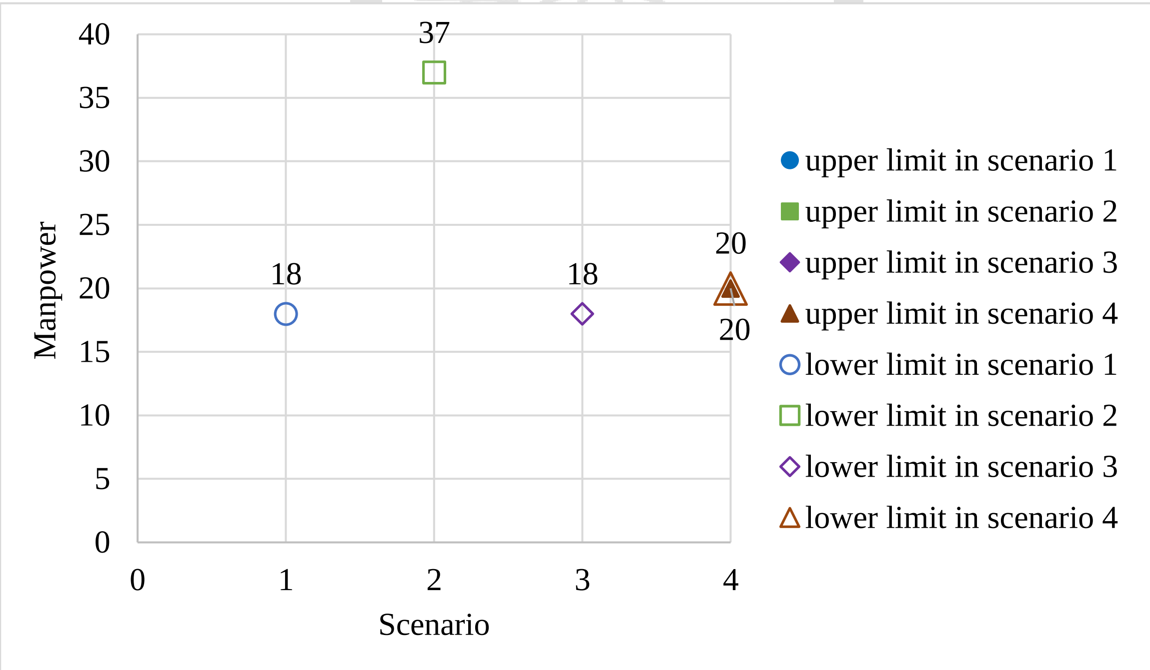

Figure 4-4 Ranges of the maximum manpower in each scenario

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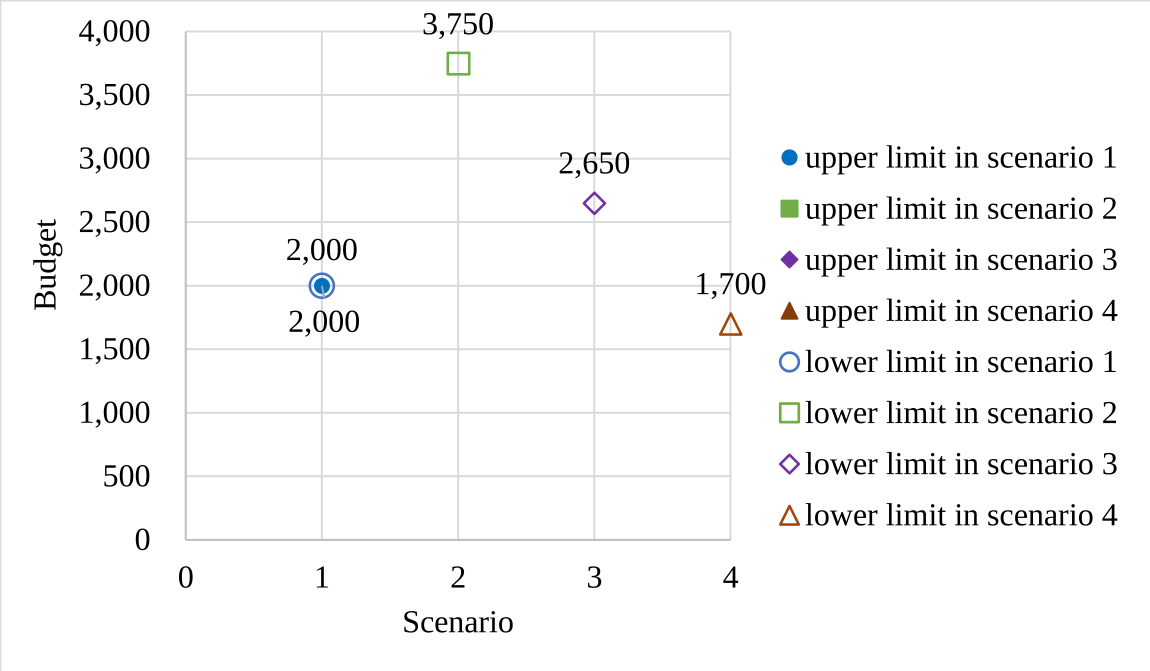

Figure 4-5 Ranges of the maximum budgets in each scenario

Based on sensitivity analysis in each scenario, the ranges of each resource are shown in Figure 4-4 and Figure 4-5. In the scenario 1, if the maximum manpower is restrained to lower than 18, the first deleted strategy will be "develop reporting procedures or regulations" (A3). The same situation will occur if the maximum budget is reduced to lower than NTD 20 million. In the scenario 2, "strengthen safety inspection mechanism in restricted areas" (R2) is the first deleted strategy in both situations of the restraint on maximum manpower and maximum budget. In the scenario 3, "increase efficiency of violation enforcement" (A2) is the first deleted strategy in both situations of the restraint on maximum manpower and maximum budget. In the scenario 4, if the maximum manpower is restrained to lower than 20, the first deleted strategy will be "continuously improve operators' skills" (E2). If the maximum budget is restrained to lower than NTD 17 million, the first deleted strategy will be "strengthen law enforcement personnel's ability of hazard identification and evaluation" (R1). Therefore, the CAA can take the results as references when considering the resource allocation.

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4.6 Summary

In this chapter, this research analyzes the relative importance and achievability of drone management strategies. Setting safety performance targets is the most important strategy, on which the CAA should make more effort. Through the overall ranking, the different viewpoints of the industry, the government, and the academia can reach a consensus.

With the importance-achievability analysis, this research offers the priority of drone management strategies for the CAA. Strategies in the dimension of safety policy and objectives belong ether the top priority implementation zone or the key challenge zone, which means the CAA should implement these strategies first.

Finally, through the ZOGP and sensitivity analysis, the results of selected strategies in different scenarios are summed up in Table 4-19.

Strategies with high importance and high achievability may still not be selected because of the limited resources. There are three strategies selected in the four scenarios, including “set safety performance targets”(P1), “integrate drone information system”(P4), and “promote drone education programs”(E3). These three strategies should be conducted first. The CAA can refer to the results before allocating resources to the drone management strategies, and efficiently improve the safety and reliability levels of drones.

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Table 4-19 Selected strategies in each scenario

Strategy	Importance ranking	Achievability ranking	Scenario			
			1	2	3	4
(P1) Set safety performance targets	1	7	√	√	√	√
(P3) Assign testing and certificating authorities	4	3	√	√	√	
(P4) Integrate drone information system	3	8	√	√	√	√
(R1) Strengthen law enforcement personnel's ability of hazard identification and evaluation	9	11		√		√
(R2) Strengthen safety inspection mechanism in prohibited areas	6	10		√		
(R3) Implement crash-avoidance technology	10	13				
(A1) Implement the drone operation tracking system	12	9				
(A2) Increase efficiency of violation enforcement	11	4		√	√	
(A3) Develop reporting procedures or regulations	13	2	√	√		
(E1) Construct drone safety culture	8	12				
(E2)Continuously improve operators' skills	7	5		√	√	√
(E3) Promote drone education programs	5	6	√	√	√	√

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Chapter 5 Conclusion

It is important for the CAA to prioritize and categorize drone management strategies to ensure the effective implementation. In this research, we evaluated, prioritized, and categorized drone management strategies based on the viewpoints of industry, government, and university experts. In particular, the combination of the relative importance and achievability results can reflect the practical effects to implementation. The ZOGP also provides the CAA a reference when allocating resources. The government can also cooperate with the industry based on the results. This is indeed a contribution to both industry and government. The outcome of this research will also help other countries gain a strategic understanding of drone management and help them draft a management plan for implementing their own strategies.

5.1 Summary of Key Findings

The key findings can be drawn that reflect the purposes of this study as below:

1. Exploring the drone management strategies by literature review, and adjusting them through the expert questionnaires.

Through literature review, this research generalizes 16 drone management strategies by using 3E principle (Education, Engineering, and Enforcement) and policy as the dimensions. After the first-stage questionnaire, the dimensions of this research are revised to ICAO's four pillars of aviation safety management systems. Some strategies are removed because of inappropriateness, while some strategies are included by the experts' suggestions. Finally, this research recommends 13 drone management strategies with the dimensions of ICAO's four pillars.

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2. Evaluating the priority of the drone management strategies through the expert questionnaires, and comparing the viewpoints of the industry, government, and academia.

With the second-stage questionnaire, this research analyzes the relative importance by FAHP. The overall top-5 ranking strategies are “set safety performance targets” (P1), “gear regulations to the international conventions” (P2), “integrate drone information system” (P4), “assign testing and certificating authorities” (P3), and “promote drone education programs” (E3). The viewpoints of the industry, government, and academia are discussed in 4.2.

Importance-Achievability Analysis is applied in this research. By establishing the four quadrants of the importance-achievability grid, the CAA can prioritize drone management strategies. There are four strategies in the top priority implementation zone, including “set safety performance targets” (P1), “gear regulations to the international conventions” (P2), “assign testing and certificating authorities” (P3), and “promote drone education programs” (E3).

3. Evaluating the resources allocation in different scenario to make the most use of the resources on the strategies.

This research further analyzes the resource allocation through the zero-one goal programming. In the four scenarios, some strategies with high importance and achievability may fail to be selected because of the limited resources. For example, “continuously improve operators’ skills” (E2) is not selected in scenario 1. The results can serve as a good reference for the CAA to draft a management plan and allocate finite resources to the right management strategies.

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5.2 Suggestions

Regarding to the results, there are some suggestions provided to the government, industry, and future research, shown as follows:

1. Suggestions to the central government

The priority of drone management strategies provided in this research can be a good and practical checklist for government to examine the strategies of drone management. According to the outcomes of ZOGP, the central government can make the best resource allocation. Since the policy can influence both the achievability of the drone management strategy in the local government and the development of the industry, the central government should set a model for reference and provide assistance instead of squelching the use of drones or even intervening the operation. In the US, if the violation poses an imminent threat to public safety, people are suggested to report all the incidents to the FAA for investigation. The CAA should follow this policy, collect all drone incident reports, and set the safety performance targets for improvement.

2. Suggestions to the local government

The local government should follow the central government's rules and adjust them properly. In the US, the local law can involve reckless endangerment, noise violations, drug smuggling, obstruction of law enforcement, and peeping tom violations. The central government may not be familiar with the dense population areas. The local government can ether amend the local regulation or suggest the central government to set the dense population areas as the prohibited areas. A traffic management platform can also be another options for the local government. In China, the Shenzhen city has promote a trial traffic management program in November, 2018. The Shenzhen local government build the platform to linking the management systems of the Air Force, the Civil

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Aviation Administration of China, and the municipal government to offer services including quick approvals of flight applications, real-time flight paths, quick verification of aircraft identity, and information broadcasting (Mo, 2018). Moreover, the local government can promote the drone safety culture through propaganda or education programs.

3. Suggestions to the industry

According to the suggestions from the experts in the first-stage questionnaire, the industry plays a vital role in drone management. Since the lack of manpower in the CAA, some strategies must be carried out with the assistance of associations, such as "assign testing and certificating authorities" (P3). The associations should keep long-tern effective two-way communication with the government to assist the government in promoting policies and regulations.

4. Suggestions to future research

There are some limitations in this research. The strategies mentioned in this research may become not enough as new technology is introduced. The new strategies need to be developed according to the situation. Because the questionnaire is distributed to experts, the opinion from the public is lack and needs to be confirmed. It is suggested that future research can investigate the opinion from the public. Furthermore, the evaluation of the performance and effectiveness of strategies can be another issue. The evaluation value can be an important reference for the government before the implementation of strategies.

5.3 Research contributions

Most research develops drone management strategies through literature review. In Taiwan, this research is the first research which systemically identifies the drone

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management strategies based on the four pillars of SMS from the viewpoint of the industry, the government, and the academia. According to the opinions from the experts, this research proves that the four pillars of SMS are more suitable to be served as the framework of drone safety management strategies than the 3E principle. Through IAA, this research further prioritizes the strategies for reference. The ZOGP brought up in this research can also be applied and adjusted in different situations. The combination of FAHP, IAA, and ZOGP is a novel approach to solve the strategy selection decision problem. The CAA can easily understand what to do instead of wasting resources and time. This is definitely a great contribution for the CAA to make the most of the limited resources. The government and the industry can gain deeper understanding to each other based on the results. Last but not least, the results can also assist other countries in handling drone issues.

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Appendix A

臺灣民用遙控無人機安全管理策略之評估　第一階段問卷

敬啟者，您好：

本研究為國立成功大學交通管理科學所之碩士論文—「臺灣民用遙控無人機管理策略評估之研究」。

自民國 107 年 4 月民用航空法修正案三讀通過後，遙控無人機正式納入政府管理，並將於民國 108　年 7 月起施行。為安全管理遙控無人機，本研究透過文獻回顧的方式，將 16 項遙控無人機管理策略分為四大構面：「**政策監理**」、「**教育宣導**」、「**工程技術**」、「**執法取締**」。期透過此問卷分析結果，找出遙控無人機管理中各項策略的重要度及可行性，以利相關單位將有限的資源做有效的運用。

本研究問卷分為二階段，此為**第一階段問卷**，需協請您就本研究提出的四大構面及十六項策略及定義，提出您專業的看法，如各項策略中有不妥、語意不清、或是任何需要修正的地方，請您在「**表一 遙控無人機安全管理策略之說明**」中的「**建議**」欄位留下您的意見。敬請您於民國 **107 年 12 月 14 日**前填寫完畢並寄回問卷，感謝您撥冗惠賜指教。

非常感謝您的協助！

敬祝

身體健康 平安順利

國立成功大學 管理學院 交通管理科學系研究所

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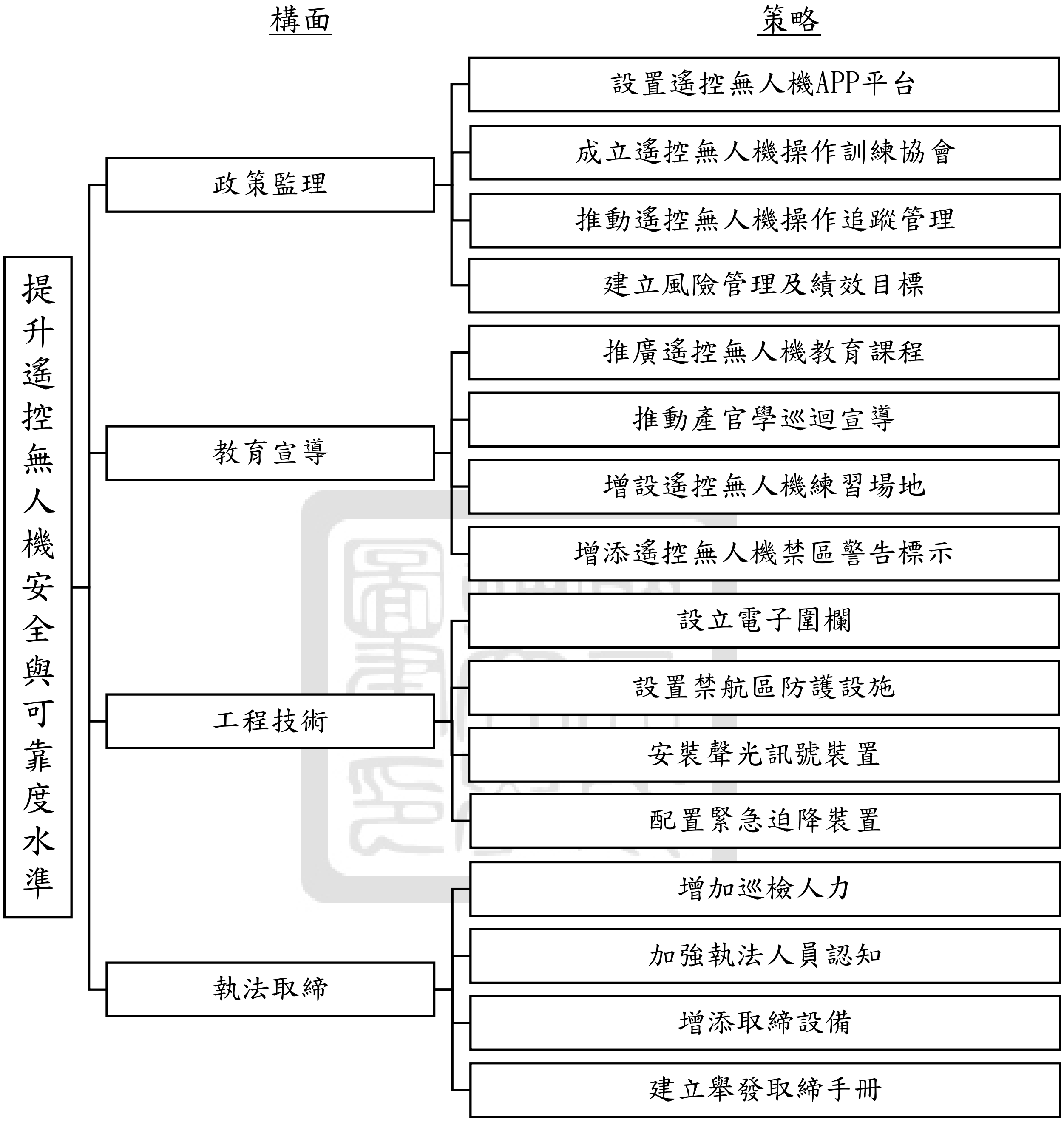
【附件】



圖一 遙控無人機安全管理策略之架構圖

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表一 遙控無人機安全管理策略之說明

構面	策略	說明	建議
政策監理	設置遙控無人機 APP 平台	設置遙控無人機 APP，使操作者能在所處位置或指定位置上，獲得明確操作指南與安全警示，同時了解相關安全法律。	
	成立遙控無人機操作訓練協會	鼓勵成立遙控無人機操作訓練協會，將操作者納入協會統一管理，建立正確安全觀念。	
	推動遙控無人機操作追蹤管理	建立追蹤管理系統，透過即時通報或是事後通報的方式，以便中央及地方單位掌控遙控無人機使用情況，並做出適當改善措施。	
	建立風險管理及績效目標	透過紀錄遙控無人機的大小事件，甚至是訂定安全指標，以供後續的檢討與改善。	
	本構面其他建議		
教育宣導	推廣遙控無人機教育課程	結合高中或大專院校開設遙控無人機操作訓練課程，提供安全飛行的觀念與技術，並了解相關安全法律。	
	推動產官學巡迴宣導	協同相關專家至社區、企業、政府單位等地進行巡迴宣導。	
	增設遙控無人機練習場地	設立遙控無人機練習場，供操作者飛行訓練、提高技巧，也為操作者提供交流心得的空間。	
	增添遙控無人機禁區警告標示	應當公佈遙控無人機禁飛區域，在區域邊界、路口等醒目位置設立禁飛標示牌，並註明淨空保護相關規定，便於民眾辨識。	
	本構面其他建議		

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構面	策略	說明	建議
工程技術	設立電子圍欄	在無人機內安裝電子圍欄，阻攔遙控無人機飛入劃定的特定區域。	
	設置禁航區防護設施	在機場周圍或是其他禁航區設置無人機防禦系統，例如：英國在特定機場使用 AUDS 系統，該系統可以阻斷遙控無人機通訊。	
	安裝聲光訊號裝置	遙控無人機要能在飛行中被清楚識別、裝有預防碰撞的指示燈、或出現操作故障時能發出警報。	
	配置緊急迫降裝置	如果失去動力或重要零件故障，遙控無人機必須能夠利用降落傘或其他方式安全降落。	
	本構面其他建議		
執法取締	加強巡檢人力	相關單位可以在禁航區增添人力，以利於加強宣傳、定期巡防。	
	加強執法人員認知	安排教育訓練課程或是提供相關訊息，幫助各地執法人員能有清楚的認知，進而避免民航局另外派人協助處理事件的狀況。	
	增添取締設備	增購干擾槍、捕捉網等取締設備，提高執法效率。	
	建立舉發取締手冊	提供民眾及執法單位指南或手冊，使其有所依循，以降低誤報的情況，例如：美國 FAA 提供相關指南，確保執法過程的完整性。	
	本構面其他建議		

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受訪者基本資料

姓名：________________

聯絡方式：(e-mail)____

(電話)____

您目前的任職單位：___________________________ 任 職 年 資 ：_______年

您目前的職務(職稱)：_________________________ 目前職務年資：_______年

過去相關經歷：

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若有其他寶貴意見，請書寫於下方空白處：

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【本問卷到此結束，謝謝您的填答】

請將問卷放入回郵信封內，於您方便時盡速寄出，誠摯地感謝您的協助！

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Appendix B

臺灣民用遙控無人機安全管理策略之評估　第二階段問卷

各位專家，您好：

本研究為國立成功大學交通管理科學所之碩士論文─「臺灣民用遙控無人機安全管理策略評估之研究」。

本研究希望藉由您的專業知識及寶貴意見評估臺灣民用遙控無人機之各項管理策略重要度與可行性，作為國內外實行時之參考。

問卷所有資料僅作為學術研究參考之用，絕不對外公開。本研究需要您的專業建議及指導，敬請您於 2019 年 2 月 27 日前填寫完畢並寄回問卷，感謝您撥冗惠賜指教。非常感謝您的協助！

敬祝

身體健康　平安順利

國立成功大學 管理學院 交通管理科學研究所

指導教授 張有恒 博士

研 究 生 林建宏 敬上

【問卷填寫說明】

1. 自民國 107 年 4 月民用航空法修正案三讀通過後，遙控無人機正式納入政府管理，並將於民國 108 年 7 月起施行。為安全管理遙控無人機，本研究透過文獻回顧及蒐集專家意見的方式，將 13 項遙控無人機管理策略分為四大構面：「安全政策與目標」、「安全風險管理」、「安全保證」、「安全提升與教育」。期透過此問卷分析結果，找出遙控無人機管理中各項策略的重要度及可行性，以利相關單位將有限的資源做有效的運用。
2. 附件圖一為本研究構面與策略之架構，表一為策略之定義說明。
3. 本問卷分成兩個部份，第一部份為「構面及策略重要性評估」，第二部份為「各策略之可行性評估」，皆有範例說明，敬請耐心填答。
4. 為感謝您協助完成本問卷，本研究將略致薄酬，以示謝忱。為帳目核銷程，請於「國立成功大學綜合所得收據」內受領人簽章處簽章，並填寫身分證字號、戶籍地址及通訊地址後，隨同問卷寄回，再次感謝您的協助。

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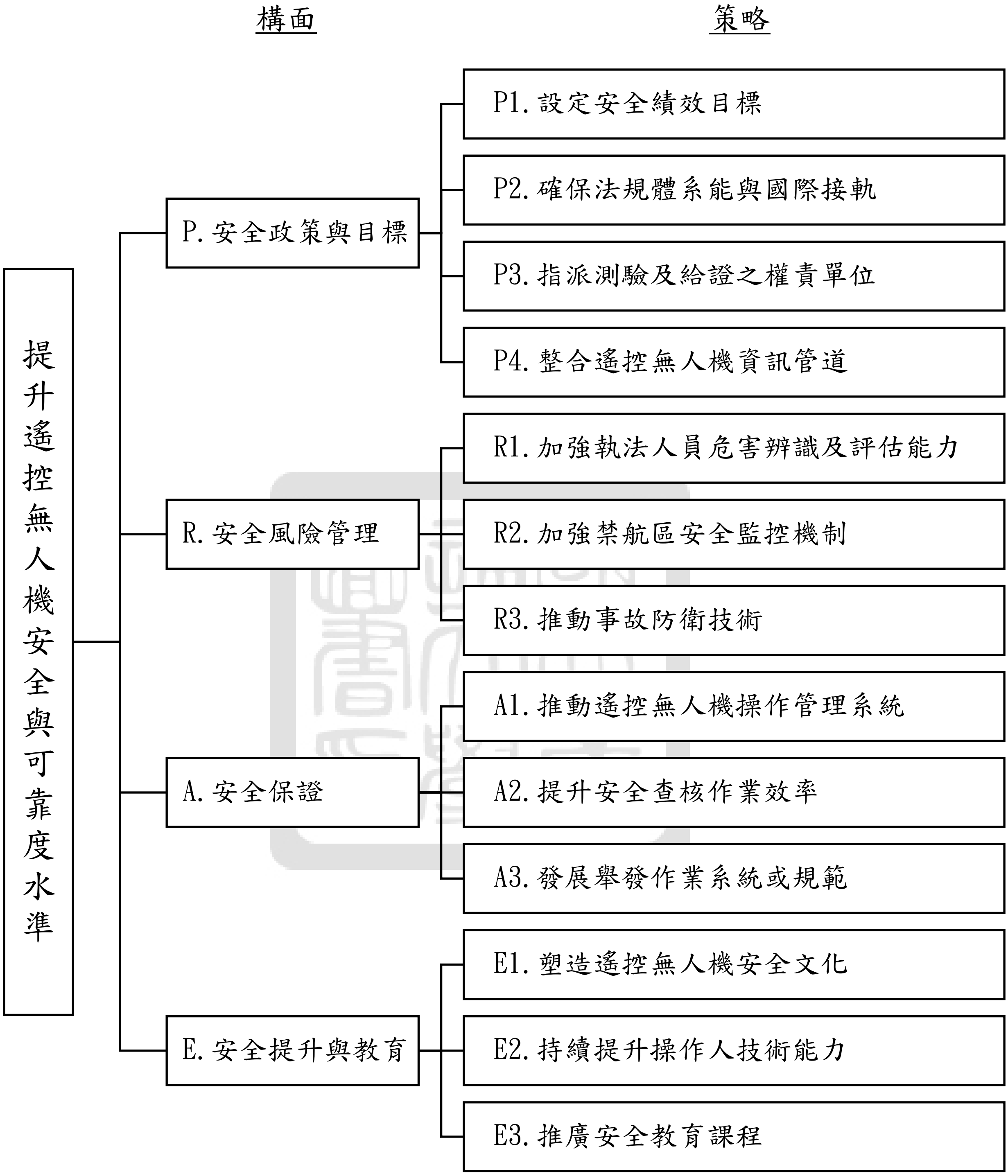
【附件】



圖一 遙控無人機安全管理策略之架構圖

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表一 遙控無人機安全管理策略之說明

構面	策略	說明
安全政策與目標(P)	設定安全績效目標	透過紀錄遙控無人機的大小事件，將其納入民航局飛安統計資料，甚至是訂定安全指標及績效值，以供後續的檢討與改善。
	確保法規體系能與國際接軌	因應環境變遷，隨時檢討遙控無人機相關管理法規，與國際接軌，並立法保障合法操作人。
	指派測驗及給證之權責單位	由民航局委託現有協會或是學校單位，或是成立操作訓練機構，將操作人納入機構統一管理，建立正確飛航安全觀念，並由民航局督責給予測驗、給證。
	整合遙控無人機資訊管道	結合禁航區、限航區、法規、氣象等資訊，提供 APP 或網頁等多元管道，以利飛行前預做規劃、飛航程序申請或設定導航。
安全風險管理(R)	加強執法人員危害辨識及評估能力	由民航局或委託代訓機構安排教育訓練課程並提供執法手冊，提升執法人員危害辨識及評估能力。
	加強禁航區安全監控機制	由硬體軟體方面著手，加強禁航區安全監控，例如：設置自動化偵測裝備、電子圍欄、增添人力等。
	推行事故防範技術	為避免無人機因失去動力或重要零件故障，而墜落導致人員及財產損害，可要求一定重量或在特定空域執行飛行任務的遙控無人機加裝迫降裝置，使遙控無人機能夠利用降落傘或其他方式安全降落。
安全保證(A)	推動遙控無人機操作管理系統	建立線上管理系統，透過即時通報或是事後通報的方式，以便各管理單位了解遙控無人機使用情況，並能督導飛航安全。
	提升安全查核作業效率	提高禁限航區遙控無人機違規飛行的取締效率，可透過增購干擾槍、捕捉網等取締設備之方式進行。
	發展舉發作業系統或規範	為避免民眾誤報的情形發生，可要求業者在包裝上張貼警語，並在民航局網頁提供連結指南或手冊，使民眾有所依循，例如：美國 FAA 提供舉發指南，確保舉發過程的完整性。
安全提升與教育(E)	塑造遙控無人機安全文化	協同相關專家至社區、企業、政府單位等地進行巡迴宣導，或是由民航局提供補助，鼓勵各地協會機構進行宣導，提升民眾對於遙控無人機之安全觀念。
	持續提升操作人技術能力	提供民眾能隨時練習或訓練的管道，可由民航局或委託機構設立遙控無人機練習場，供操作者飛行訓練、提高技巧，也為操作人提供交流心得的空間。
	推廣安全教育課程	推廣安全飛行的觀念與技術，使民眾了解相關安全法律，可由民航局或是其督責單位結合學校單位開設遙控無人機操作訓練課程或職訓課程。

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<u>第一部分：構面及策略重要性評估</u>

【問卷填寫說明】

層級分析法的實務操作邏輯乃是「必須秉持因素間相對重要性排序的一致性」，填答過程的排序失誤會導致「廢卷」的遺憾，於下以條列方式提供問卷填答說明：

1. 建議按問卷提問順序填答，避免排列順序混淆的現象，並請先就同層級之各項要素依影響的重要性排列順序。

2. 比較時須符合遞移性，若 A 比 B 重要(A>B)，且 B 比 C 重要(B>C)，則 A 也要比 C 重要(A>C)，意即 A>B>C 必須成立。

【範例】

若您認為左邊的指標重要性較大，請在偏左的適當強度中勾選；若您認為右邊的指標重要性較大，請在偏右的適當強度中勾選。(每一列僅勾選一項)。例如，假設您選購手機時，考慮的因素為 1.品牌、2.價格、3.外型等三項，若您覺得3.外型比2.價格重要，且2.價格比1.品牌重要，則3.外型≧2.價格≧1.品牌，填寫方式如下所示：

(1) 請依重要性排序(填數字序號即可)：（3）≧（2）≧（1）

(2) 請依上述排序，勾選兩兩因素的「相對重要程度」。(重要性強度需與上題項所填寫之順序結果邏輯相符)

準則 A	重要性程度 A：B																	準則 B
	絕強		極強		頗強		稍強		同		稍弱		頗弱		極弱		絕弱	
尺度	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	尺度
品牌												✓						價格
														✓				外型
價格											✓							外型

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【問卷內容】請依序回答下列問題並完整填寫

一、各項構面間之相對重要性比較

針對臺灣民用遙控無人機管理策略之構面而言，請就「P.安全政策與目標」、「R.安全風險管理」、「A.安全保證」以及「E.安全提升與教育」四個構面評估其相對重要程度。

1. 請依重要性排序(填入英文代號即可)：(　) ≧ (　) ≧ (　) ≧ (　)
2. 請依上述排序，以成對比較方式勾選兩兩構面間的「相對重要程度」。

構面 A	重要性程度 A：B																	構面 B
	絕強		極強		頗強		稍強		同		稍弱		頗弱		極弱		絕弱	
尺度	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	尺度
安全政策與目標(P)																		安全風險管理(R)
																		安全保證(A)
																		安全提升與教育(E)
安全風險管理(R)																		安全保證(A)
																		安全提升與教育(E)
安全保證(A)																		安全提升與教育(E)

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二、各項策略間之相對重要性比較

1. 針對「安全政策與目標」構面而言，請就「1.設定安全績效目標」、「2.確保法規體系能與國際接軌」、「3.指派測驗及給證之權責單位」以及「4.整合遙控無人機資訊管道」四個策略評估其相對重要程度。

(1) 請依重要性排序(填入數字序號即可)：(　　) ≧ (　　) ≧ (　　) ≧ (　　)

(2) 請依上述排序，以成對比較方式勾選兩兩策略間的「相對重要程度」。

策略 A	重要性程度 A：B																	策略 B
	絕強		極強		頗強		稍強		同		稍弱		頗弱		極弱		絕弱	
尺度	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	尺度
設定安全績效目標(P1)																		確保法規體系能與國際接軌(P2)
																		指派測驗及給證之權責單位(P3)
																		整合遙控無人機資訊管道(P4)
確保法規體系能與國際接軌(P2)																		指派測驗及給證之權責單位(P3)
																		整合遙控無人機資訊管道(P4)
指派測驗及給證之權責單位(P3)																		整合遙控無人機資訊管道(P4)

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2. 針對「安全風險管理」構面而言，請就「1.加強執法人員危害辨識及評估能力」、「2.加強禁航區安全監控機制」以及「3.推行事故防範技術」三個策略評估其相對重要程度。

(1) 請依重要性排序(填入數字序號即可)：(　　) ≧ (　　) ≧ (　　)

(2) 請依上述排序，以成對比較方式勾選兩兩策略間的「相對重要程度」。

策略 A	重要性程度 A：B																	策略 B
	絕強		極強		頗強		稍強		同		稍弱		頗弱		極弱		絕弱	
尺度	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	尺度
加強執法人員危害辨識及評估能力(R1)																		加強禁航區安全監控機制(R2)
																		推行事故防範技術(R3)
加強禁航區安全監控機制(R2)																		推行事故防範技術(R3)

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3. 針對「安全保證」構面而言，請就「1.推動遙控無人機操作管理系統」、「2.提升安全查核作業效率」以及「3.發展舉發作業系統或規範」三個策略評估其相對重要程度。

(1) 請依重要性排序(填入數字序號即可)：(　)≧(　)≧(　)

(2) 請依上述排序，以成對比較方式勾選兩兩策略間的「相對重要程度」。

策略 A	重要性程度 A：B																	策略 B
	絕強		極強		頗強		稍強		同		稍弱		頗弱		極弱		絕弱	
尺度	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	尺度
推動遙控無人機操作管理系統(A1)																		提升安全查核作業效率(A2)
																		發展舉發作業系統或規範(A3)
提升安全查核作業效率(A2)																		發展舉發作業系統或規範(A3)

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4. 針對「安全提升與教育」構面而言，請就「1.塑造遙控無人機安全文化」、「2.持續提升操作人技術能力」以及「3.推廣安全教育課程」三個策略評估其相對重要程度。

(1) 請依重要性排序(填入數字序號即可)：(　)≧(　)≧(　)

(2) 請依上述排序，以成對比較方式勾選兩兩策略間的「相對重要程度」。

策略 A	重要性程度 A：B																	策略 B
	絕強		極強		頗強		稍強		同		稍弱		頗弱		極弱		絕弱	
尺度	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	尺度
塑造遙控無人機安全文化(E1)																		持續提升操作人技術能力(E2)
																		推廣安全教育課程(E3)
持續提升操作人技術能力(E2)																		推廣安全教育課程(E3)

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第二部分：各策略之可行性評估

【問卷填寫說明】

1. 此部分為各策略相對重要性之延伸，在您填完相對重要性後，本研究想了解您認為「臺灣民用遙控無人機管理策略」各策略之可行性為何，此部分只有可行性之評估，無相對之比較。

2. 本研究採用「很低」至「很高」五個尺度，**尺度值越大，越趨近於高或很高的程度，表示此策略越容易執行，反之則趨低於低或很低的程度，表示策略執行難度較高。**

【範例】

	很低	低	中	高	很高
可行性分數	0~20	20~40	40~60	60~80	80~100
			✓		

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【問卷內容】請完整填寫

構面	管理策略	改善可行性分數				
		很低	低	中	高	很高
		0~20	20~40	40~60	60~80	80~100
安全政策與目標(P)	(P1)設定安全績效目標					
	(P2)確保法規體系能與國際接軌					
	(P3)指派測驗及給證之權責單位					
	(P4)整合遙控無人機資訊管道					
安全風險管理(R)	(R1)加強執法人員危害辨識及評估能力					
	(R2)加強禁航區安全監控機制					
	(R3)推行事故防範技術					
安全保證(A)	(A1)推動遙控無人機操作管理系統					
	(A2)提升安全查核作業效率					
	(A3)發展舉發作業系統或規範					
安全提升與教育(E)	(E1)塑造遙控無人機安全文化					
	(E2)持續提升操作人技術能力					
	(E3)推廣安全教育課程					

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受訪者基本資料

姓名：________________

聯絡方式：(e-mail)____

(電話)____

您目前的任職單位：___________________________　任 職 年 資 ：_______年

您目前的職務(職稱)：__________________________　目前職務年資：_______年

過去相關經歷：

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若有其他寶貴意見，請書寫於下方空白處：

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【本問卷到此結束，謝謝您的填答】

請將問卷放入回郵信封內，於您方便時盡速寄出，誠摯地感謝您的協助！

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