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Effectively Integrating UAVs into the Wildfire Emergency Management System in China: Case Study of Sichuan Province

Master Thesis

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Abbreviations

EM	Emergency Management
H-EMLC	Hazard Emergency Management Life Cycle
LiDAR	Light Detection and Ranging
MEM	Ministry of Emergency Management
NFGA	National Forestry and Grassland Administration
PPC	People's Republic of China
RS	Remote Sensing
TOE	Technology-Organisation-Environment
UAS	Unmanned Aerial System
UAVs	Unmanned Aerial Vehicles
UN	The United Nations
WEM	Wildfire Emergency Management
WM	Wildfire Management
WSNs	Wireless Sensor Networks

1 Introduction

1.1 Background and motivation

Recent years have seen a significant rise in both the frequency and severity of wildfires globally, presenting substantial risks to human life, economic stability, and ecosystems (Bushnaq, Chaaban & Al-Naffouri, 2021; Akhloufi et al., 2021; Stoof & Kettridge, 2022). The United Nations (UN) predicts global extreme fires to increase by 14% by the end of 2030, 30% by 2050, and as much as 50% by the end of the century (Institute for Defense & Government Advancement, 2024). Climate change, land use change, extreme heat, and severe drought conditions have further exacerbated wildfire risks and intensified the global need for advanced and responsive wildfire emergency management (WEM) systems (Chen et al., 2019).

Traditional wildfire detection and monitoring methods, including satellite imaging, remote cameras, and manual ground inspections, demonstrate considerable limitations such as detection delays, inadequate reliability, and low spatiotemporal resolution, which frequently hinder the effectiveness of early fire response (Bushnaq et al., 2021). To overcome these shortcomings, unmanned aerial vehicles (UAVs) or drones have emerged as a promising technological advancement globally. Recent research primarily emphasises the technology advancements in modern WEM (Boroujeni et al., 2024; Momeni & Mirzapour Al-e-Hashem, 2024), with research methods on simulation (Lambert et al., 2024) and field studies (McKenna et al., 2017). The benefits of drones are explicitly reflected in effectively improving wildfire detection, assessment, and suppression by providing real-time situational awareness and facilitating effective monitoring (Boroujeni et al., 2024; Afghah et al., 2019). While these studies advance the technical understanding of UAVs, covering flight endurance, payload capacity, and fire detection algorithms, often emphasising algorithmic precision and hardware configuration (Boroujeni et al., 2024). However, there is limited empirical research on how UAVs are actually integrated into wildfire governance structures, especially in hierarchical and uneven resource-allocation settings like Sichuan.

Although China leads the world in the number of domestically registered drones, which exceeds 1 million by 2023 (National Development and Reform Commission, 2024), it exhibits fragmentation in its drone technology for WEM systems, resulting in limited practical applications. In Sichuan Province, which is experiencing an increasing threat of wildfires due to its unique terrain and climate conditions, traditional ground patrols and personnel suppression approaches still dominate emergency management, indicating a large gap between existing technical capabilities and actual operations.

The Ministry of Emergency Management (MEM) and the National Forestry and Grassland Administration (NFGA) have emphasised the need for expanding drone applications within China's forest fire management system (Ministry of Emergency Management, 2024). Nonetheless, real integration is still constrained and insufficiently examined, particularly from the strategic, organisational, and regulatory dimensions. Sichuan Province is actively procuring integrated fire management systems; however, drones are primarily utilised as supplementary data sources rather than as fully integrated strategic tools for comprehensive wildfire management across multiple phases. As a result, their system effectiveness in the prevention, detection, suppression, and recovery phases remains inadequately assessed.

This research is motivated by the inadequate qualitative research gap and the UAV integration gap. While UAVs hold promise for improving disaster preparedness and response, their deployment is mediated by organisational capabilities, regulatory structures, and technological infrastructure—areas underexplored in existing literature. Thus, this thesis examines the integration of UAVs into Sichuan’s wildfire management system through the lens of the Technology–Organisation–Environment (TOE) framework and the Hazard Emergency Management Life Cycle (H-EMLC) theory.

By investigating the perceptions and practices of multiple stakeholders, including UAV operators, community-level patrol workers, and regional WEM managers, this study contributes to both academic and policy discourse. It offers novel insight into how emerging technologies interact with local WEM organisations in a real-world setting, aiming to inform more adaptive, technology-enabled emergency systems in China and similar contexts globally.

1.2 Research questions

Based on the above section, come up with the following research question:

What are the opportunities and challenges to effectively integrating UAVs into existing WEM systems across their life cycles?

To answer the main question comprehensively, the author posed additional sub-questions as follows:

1. *What are the technical strengths and limitations of UAVs in Sichuan's WEM?*

The UAVs in this question are seen as technical instruments to assess their technical strengths and limitations on functionality, characteristics, and accessibility. Although there is a amount of study on the assessment of technical capability from different aspects, there is a necessity to conclude its role from the technical sights to explore the possibility of integration over traditional WEM methods in different phases.

2. *What are the opportunities and challenges for integrating UAVs into Sichuan's WEM system within organisational and environmental contexts?*

This question is prone to focus on the external elements that influence the integration of UAVs from the wildfire management sector in Sichuan Province on its decision-making structure, communication process, and resource allocation, as well as the environmental factors, mostly focusing on government regulation on aerial operation, privacy protection, and ecological protection.

3. *How can UAVs enhance WEM capability across all life cycles in Sichuan efforts?*

After assessing how these three intertwined dimensions influence the integration of UAVs and based on the life cycle theory, to explore each stage with Sichuan Province on how UAVs enhance the EM sector capability.

1.3 Research objectives

Therefore, this study aims to investigate UAV integration in the WEM system in China, focusing on Sichuan Province as a background case study. The study explores the technological, organizational, and environmental factors that affect UAV adoption and evaluates their effectiveness across different phases of the wildfire emergency management life cycle.

To achieve this, the research will do the following:

1. Clearly define core concepts related to wildfire management and UAV integration using existing literature in English and Chinese;

2. Systematically collect and analyse current governmental policies, regulations, and industry reports regarding UAV deployment within wildfire emergency management;

3. Conduct literature review, identifying theoretical and practical knowledge gaps in UAV applications within the emergency management lifecycle;

4. To describe and justify the chosen research methodology, ensuring rigorous and transparent data collection and analysis procedures;

5. To collect qualitative data from key stakeholders (UAV operators, ground-patrol workers, emergency managers) to gain in-depth insights into operational practices, organizational readiness, and regulatory challenges;

6. To analyze and interpret qualitative data using thematic analysis, guided by the TOE framework and H-EMLC theory, thereby identifying the key technological, organizational, and environmental factors influencing UAV integration.

7. Documenting the final version of the thesis before June 2, 2025.

1.4 Significance of the study

This study significantly enhances the theoretical and practical understanding of UAV integration in wildfire emergency management systems, specifically in Sichuan Province, China. Theoretically, it fills a research methodological and knowledge gap in the qualitative understanding of systematically implementing drone technology into multi-stage wildfire management by explicitly examining technological, organisational, and environmental dimensions. Practically, this study extends the current academic discussion on technology integration within the public sector emergency management framework by providing valuable case experiences and practical implications for other regions encountering comparable wildfire threats and technology integration challenges. The findings serve as a valuable reference for enhancing WEM capabilities in Sichuan Province and may also be applicable to other regions with similar wildfire characteristics in the future, rather than representing a generalisation of the research..

1.5 Structure of the thesis

This thesis follows a specific structure. Chapter 2 presents relevant terminologies, comprehensive conceptual explanations of wildfire management, and detailed background on Sichuan Province. Chapter 3 critically reviews existing literature on the existing research methods and theories with UAV adoption in WEM, identifying research gaps and deriving the theoretical frameworks that support this study. Chapter 4 focuses on the research design, including the research form, data collection, and data analysis methods. Chapter 5 presents empirical findings and thematic analyses. Chapter 6 will further interpret and discuss the findings and their association with the existing research. Finally, Chapter 7 summarises the key findings, acknowledges the limitations, and offers recommendations for future research.

2 Background of the study

2.1 Define the terminology

2.1.1 Wildfire

“ Wildfire” itself lacks a consistent agreement on standardised terminology in various linguistic contexts worldwide, which could create confusion across different communities. When describing fires in vegetated landscapes, examples include terms like wildfire, forest fire, vegetation fire, bushfire, and rangeland fire (Huidobro, Giessen & Burns, 2024). The terms bushfire and forest fire are used in Australia and Europe, respectively (Huidobro, Giessen & Burns, 2024). Other terms are also used to describe the same phenomenon depending on the type of vegetation burnt (landscape fire, vegetation fire, wildland fire, and grass fire) or the context they occur in (e.g., wildland-urban interface fire, rural fire, and peat fire), but the fire phenomenon as a combustion of vegetation in an open environment follows the same physical and chemical laws everywhere (Tedim & Leone, 2020).

Therefore, “wildfire” (森林草原火灾) is the standard term suggested by Huidobro, Giessen & Burns (2024) that will be used throughout this paper to describe any unplanned and uncontrolled fire started on the vegetated landscape.

Wildfires not only contribute to carbon dioxide emissions but also reduce the natural carbon sink capacity, further intensifying climate change impacts (Schinko et al., 2023). Since wildfires are unplanned fires that occur in natural ecosystems, the ignition source can be natural (mostly lightning) or anthropogenic (Haas et al., 2024), but is mainly influenced by four major factors (Khatua et al., 2025): weather conditions, fuel load and moisture content, topography and human activities.

Weather Conditions: Fluctuations in temperature, precipitation, relative humidity, and wind speed directly affect wildfire intensity, frequency, and spread (Khatua et al., 2025). These variables also influence soil moisture levels, increasing fire susceptibility in dry conditions (Khatua et al., 2025).

Fuel Load & Moisture Content: The amount and dryness of vegetation determine how easily fires ignite and propagate potentially (Khatua et al., 2025). Modern remote sensing technologies now allow for large-scale estimation of fuel moisture and distribution, enhancing fire risk assessment (Khatua et al., 2025).

Topography: Factors such as slope, elevation, and zoning across fires and resources at risk (Thompson & Calkin, 2011).

Based on the variable ignition source and the influential elements, the wildfire category remains in disagreement (Tedim & Leone, 2020). Wildfires nowadays are increasingly categorised as a socio-ecological phenomenon rather than a pure natural hazard. In this context, it represents the complex interactions of people and nature during all wildfire phases, connecting people and their communities to the places they live in and the impacts they have on those environments (Tedim & Leone, 2020). This complies with the necessary understanding that in all the phases of the wildfire process (Tedim & Leone, 2020), the definition also extends with the simplification of categorised wildfires as "natural hazard", "disturbance", and "climate-sensitive hazard" (Tedim & Leone, 2020).

2.1.2 Wildfire emergency management

As a global phenomenon, wildfire emergency management (WEM) is essential to curb the destructive power of wildfires and maintain the complex ecological balance of forests (Ebrahimi et al., 2024) so that the primary goal of effective wildfire management is protecting lives, property, and the environment from the devastating effects of wildfires (Ebrahimi et al., 2024). In other words, managing wildfires is subject to various sources of uncertainty (Thompson & Calkin, 2011). These stem from the unpredictability of wildfire behavior, inaccurate or missing data, an incomplete scientific understanding of ecological response to fire, an incomplete scientific knowledge of fire behavior response to management treatments (suppression, fuel reduction, etc.), and limited resource value measures to guide prioritization across fires and resources at risk (Thompson & Calkin, 2011). The components of the WEM are mitigation, preparedness, response, and recovery (McLoughlin, 1985).

Mitigation

Despite human attempts to manage wildfire risk, mitigation as one of the most important disciplines of WEM, it is defined as sustained action to reduce or mitigate the wildfire risk as a long term solution, its opposed with preparedness for wildfire risk planning and immediate response to wildfire, but it blurs with the boundary with recovery since the mitigation strategy influence the recovery and vice versa, the recovery could be part of mitigation. However, the mitigation differentiates with other disciplines not only direct to next wildfire, but also wildfire in the future, as well as it is the broader participation and support from outside of traditional WEM (Bullock, Haddow & Coppola, 2017), such as planners and local operating departments, and private sector groups such as lending institution (Bullock, Haddow & Coppola, 2017). Several mitigation tools to reduce risks are: hazard identification and mapping, land-use planning, insurance, finance incentives, design and construction application (Bullock, Haddow & Coppola, 2017).

Preparedness

Preparedness is the state of readiness to respond to a disaster, crisis, or any kind of emergency situation (Lambert et al., 2024). For wildfire involves developing risk assessments, firefighting and evacuation plans, conducting drills, establishing communication protocols, providing training for emergency responders and the public, monitoring weather, climate, and fuel conditions, developing fire simulations using current and forecasted conditions to inform decision-making, and establishing coordinated modeling, cataloging, and presentation of information for use in fire management (Lambert et al., 2024).

Activities that develop operational capabilities for responding to an emergency (McLoughlin, 1985); for instance, emergency operations plans, warning systems, emergency operating centers, emergency communications, emergency public information, mutual aid agreements, resource management plans, and training and exercises.

Response

Activities taken immediately before, during, or directly after an emergency that save lives, minimize property damage, or improve recovery (McLoughlin, 1985). For instance, emergency plan activation, activation of emergency systems, emergency instructions to the public, emergency medical assistance, manning emergency operations centers, reception and care, shelter and evacuation, and search and rescue.

Recovery

Recovery focuses on restoring affected areas and communities to a pre-wildfire state. Key considerations include postwildfire assessments, rebuilding infrastructure, providing support to affected individuals and communities, and addressing environmental impacts through rehabilitation and restoration efforts (Lambert et al., 2024). Short-term activities that restore vital life-support systems to minimum operating standards and long-term activities that return life to normal, which can be seen as part of the mitigation strategy.

In summery, wildfire emergency management for the all level of government in partnership to address the uncertainty of wildfire and protect people and property while maintaining essential governmental functions through the emergency framework (mitigation, preparedness, response, and recovery (McLoughlin, 1985), noted that mitigation and recovery emphase on policy, political, and fund-raising skills and preparedness and response focus on decision making, communication, and direction and control skills (McLoughlin, 1985).

2.1.3 Wildfire management system in China

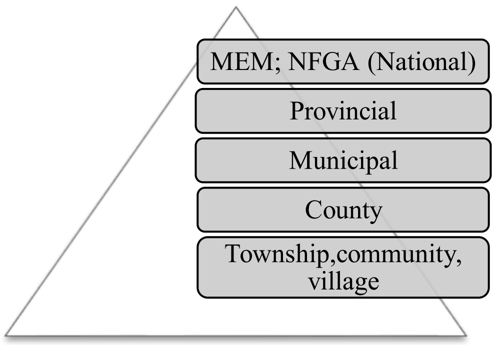
As mentioned previously, the WEM requires all levels of government agencies to complete the four disciplines and view wildfire as a social-natural phenomenon not only related to the natural elements but also requiring the human interval. Therefore, this section mainly zooms into the China's regulation and administrative structure on WEM.

Emergency management systems are interorganisational arrangements operating to mitigate, prepare, respond, and recover from emergencies (Hu, Yeo & Kapucu, 2022). It consists of organisational actors and the relationships that connect actors (Hu, Yeo & Kapucu, 2022). Such relations can include either vertical or horizontal interactions among organisations to exchange information or resources and joint efforts of organisations in completing a specific task or emergency support function regarding emergencies (Hu, Yeo & Kapucu, 2022).

Vertically, China's wildfire emergency management system is structured within the broader framework of the country-level emergency response system, emphasising a hierarchical, multi-agency approach; in other words, the emergency management plan from top-down administration as guidance influences the whole on-site downward WEM system according to different types of emergency level distinguishment.

From the 21st century, wildfire management in China has gradually established the policy discipline of "prevention first and active eradication" and "total fire control" (Lian et al., 2024). In 2016, NFGA issued the “National Forest Fire Prevention Plan (2016–2025)”, which provides a detailed narrative on how to improve the forest fire prevention construction system. In 2021, the NFGA issued the “Circular on Strengthening Forest and Grassland Fire Prevention Work in Fall and Winter Across the Country” (Ministry of Emergency Management, 2024).

Governed by the Emergency Response Law of the People's Republic of China (PPC), the system integrates national, provincial, and local governments to ensure coordinated prevention, response, and recovery efforts (Xiong et al., 2023). The MEM leads the national-level response, while specialised agencies like the NFGA oversee wildfire-specific strategies. Local governments have primary responsibility for on-the-ground implementation, supported by military forces, professional firefighting teams, and emergency volunteer groups (Lian et al., 2024).



Source: the author

Figure 2.1 WEM system in China

Local governments, structured under provincial, municipal, and county administrations (see Figure 2.1), are responsible for implementing wildfire prevention measures and executing emergency plans on the ground. These plans are categorised into national, provincial, regional, county, city or community, township, and village levels, ensuring that emergency management is tailored to local conditions and administrative divisions (Xiong et al., 2023). Recent policy developments, such as the 14th Five-Year Plan for the National Emergency System, emphasise the importance of enhancing emergency plan preparation and evaluation mechanisms at all administrative levels in a technology-driven method (Ministry of Emergency Management, 2024).

Despite the initiative and policy progress, challenges persist in optimising inter-agency coordination and ensuring the effectiveness of local-level response efforts. Integrating scientific research into predictive and preventive measures remains crucial for mitigating wildfire risks effectively (Lian et al., 2024).

2.1.4 WEM technique in China

As introduced before, the WEM in China is governed by the standardised 'Emergency Response Law of the People's Republic of China' and guided by the National Forest Fire Prevention Plan (2016–2025). This section focuses on the general WEM technique operated by the EM department, followed by the national law.

1. Green belts

Since the 21st century, China mainly implemented extensive green firebreak projects as crucial ecological tools aimed at mitigating wildfire risks in vegetated landscapes in the long term consideration. These initiatives involve strategically planting densely populated evergreen broadleaf trees along designated strips to create effective barriers against the spread of surface and crown fires (Wang et al., 2021). The magnitude of these initiatives is significant, with more than 364,000 kilometres of green firebreaks currently in place and intentions to extend this network by an extra 167,000 kilometres by 2025 (Cui et al., 2019).

Green firebreaks have multi-layered, canopy-closed structures that efficiently and economically suppress flames while promoting long-term biodiversity protection (Wang et al., 2021). This methodology highlights China's proactive strategy in wildfire management, utilising ecological solutions in conjunction with conventional fire suppression techniques (Wang et al., 2021).

Despite their advantages, challenges persist, except the increasing fuel source after the afforestation, particularly with prescribed burns, another key method in China's wildfire prevention arsenal (Wang et al., 2021).

2. Prescribed burns

Prescribed burns involve deliberately setting fires to remove combustible materials from forests, thereby reducing fuel loads and lowering the risk of catastrophic wildfires (Li et al., 2023). However, the practice poses significant challenges in decision-making, and a central issue would be the decision on how much to burn, where to burn, and how to burn (Li et al., 2023).

Moreover, the effectiveness of prescribed burns can be influenced by various factors, including weather conditions, terrain complexity, and ecological sensitivity. Remote sensing technologies have emerged as invaluable tools in this context, enabling real-time monitoring and assessment of fire patterns and extents across vast forested areas (Li et al., 2023; Boroujeni et al., 2024). These technologies facilitate efficient data collection, enhance monitoring capabilities, and inform comprehensive management strategies, thereby supporting more informed decision-making in wildfire prevention and response efforts.

In conclusion, green firebreaks and prescribed burns exemplify effective ecological strategies for wildfire management in China, and their incorporation with advanced technologies highlights the nation's comprehensive efforts to boost forest resilience and mitigate wildfire risks amid changing environmental challenges. The incorporation of modern technology into the WEM, as advocated by researchers and the MEM project, is essential for addressing the issues posed by escalating wildfire dangers.

2.1.5 UAVs in wildfire emergency management

Unmanned Aerial Vehicles (UAVs), commonly known as drones are defined by the Merriam-Webster Dictionary as "an unmanned aircraft or ship guided by remote control or onboard computers," UAVs are also referred to as Unmanned Aerial Systems (UAS), Unmanned Aircraft, and Remotely Piloted Aircraft (Tang & Shao, 2015). The term UAS emphasises the integration of onboard systems, ground control stations, and communication networks, which enable autonomous or semi-autonomous operations (Tang & Shao, 2015). UAVs can be classified by various performance characteristics (Tsouros, Bibi & Sarigiannidis, 2019), including size, weight, range and endurance, maximum altitude, engine type, and configuration (Tsouros, Bibi & Sarigiannidis, 2019).

UAVs used in wildfire management can be categorized into three main types with wing-type: fixed-wing, rotary-wing, and hybrid UAVs (Khan, Gupta, & Gupta, 2022). Each type possesses distinct advantages and limitations that affect its appropriateness for various stages of wildfire management tasks (Partheepan, Sanati, & Hassan, 2022).

- Fixed-wing UAVs resemble traditional airplanes and are characterized by longer flight endurance, higher altitude capabilities, and efficient energy consumption (Khan, Gupta, & Gupta, 2022). They are well-suited for large-scale fire monitoring and fire spread prediction but require runways or launch systems for takeoff, limiting their deployment in dense forest areas (Khan, Gupta, & Gupta, 2022).

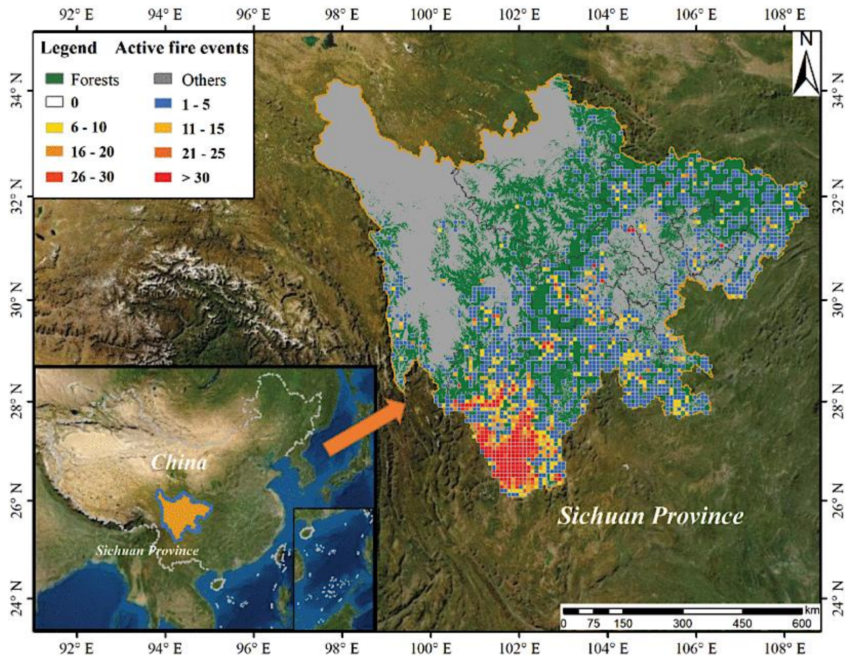
- Rotary-wing UAVs, including quadcopters and hexacopters, provide vertical takeoff and landing capabilities and can hover in place, making them ideal for detailed aerial imaging, close-range fire detection, and suppression support (Khan, Gupta, & Gupta, 2022). However, they generally have shorter flight durations and lower speeds compared to fixed-wing UAVs (Khan, Gupta, & Gupta, 2022).

- Hybrid UAVs combine the endurance of fixed-wing UAVs with the maneuverability of rotary-wing UAVs, enabling both long-distance fire surveillance and precise hovering for localized monitoring (Khan, Gupta, & Gupta, 2022). While still under development, hybrid UAVs offer promising solutions for adaptive wildfire response and multi-UAV coordination (Partheepan, Sanati, & Hassan, 2022).

The classification of UAV types is relevant in wildfire management, as their deployment varies according to the specific tasks required during different phases of a wildfire event.

2.2 Case site background

Sichuan Province (see Figure 2.2) is the second largest forest area in China with rich forestry and bio-genetic resources, located in the southwest of China (97°21′–108°33′ E, 26°03′ and 34°19′ N) (Peng et al., 2023), with 21 municipal-level administrative districts (Peng et al., 2023), and on the transitional region between the first and second rungs of overall topography (Jiao et al., 2023). According to the 2018 annual report of forestry resources and benefits monitoring of Sichuan Province, the forest area is 18.8711 million hectares, with a coverage rate of 38.83%. About 2/3 of natural forest is mainly distributed in the plateau area of Western Sichuan and the mountainous area of Southwestern Sichuan (Jiao et al., 2023), while 1/3 of artificial forests are located in the mountainous region surrounding the basin and in the basin's centre. The unique geographical setting, intricate and varied geomorphic features, and disparity in altitude result in precious and diverse forest and grassland ecosystems (Jiao et al., 2023), including cold, temperate, and coniferous forests to sub-tropical rain forests (Hayes, 2021).



Source: Peng et al. (2023)

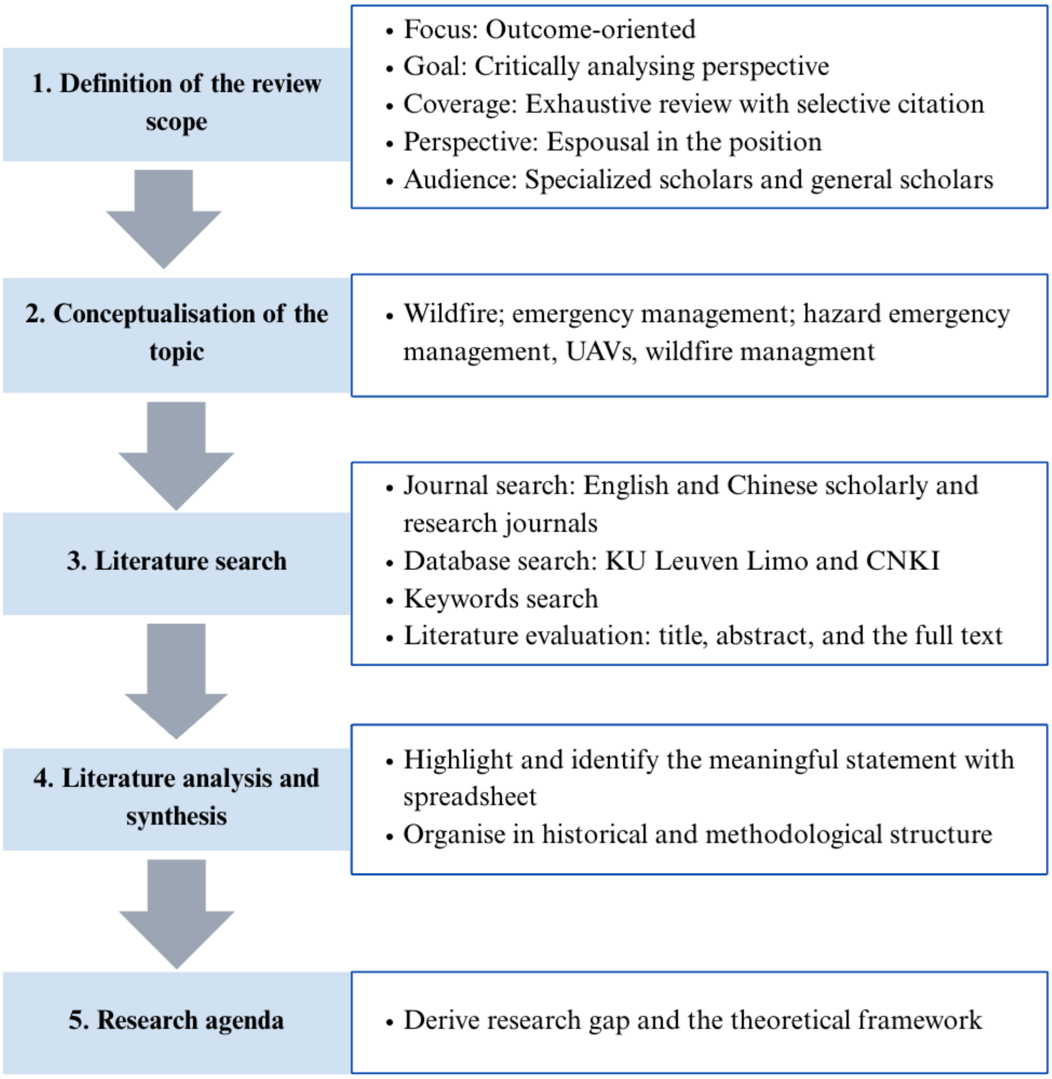
Figure 2.2 Location of the study area and historical fire density distribution (2001–2021) in forest regions

Although the frequency of wildfires in China showed a downward trend from 2003 to 2022, the frequency of wildfires in southwestern regions such as Sichuan Province showed an upward trend, highlighting a localised shift in the overall wildfire occurrence pattern in China (Lian et al., 2024). Importantly, this region is also vulnerable to fire disturbance due to the rich forest resources, complex topography, and distinctive climates are all factors that contribute to the increasing frequent occurrence of wildfires, especially the south part, and thus it has become one of the main regions in China needing to enforce wildfire prevention and monitoring capability (Peng et al., 2023). The wildfire in Sichuan Province recently caused a huge amount of property damage and casualties, such as a fire on March 30, 2020, in Xichang, Sichuan, killing 19 people and injuring 3 with direct economic losses of 97.3112 million yuan (Xinhua News Agency, 2020). Current WEM practices in Sichuan Province rely primarily on manual ground patrols, fixed checkpoints, and prescribed burning for prevention and detection. Field teams primarily conduct firefighting efforts through direct operations, with minimal use of drones. However, complex terrain, rising wildfire frequency, and restricted application of advanced technologies reveal substantial deficiencies in the efficacy of current WEM systems.

In short, the combination of geographic diversity and complexity, rising wildfire risk, and the lack of systematic, technology-driven emergency management is consistent with the purpose of this paper. Sichuan Province was selected as the case study site because it reflects both the urgent need to integrate UAV technology into the WEM system and its distinct environmental and administrative challenges. This study looks at this issue and aims to provide evidence-based insights and practical recommendations for strengthening wildfire management in similar complex, high-risk areas.

3 Literature review & theoretical framework

Conducting a literature review to demonstrate the knowledge about UAV integration in the WEM system, including the vocabulary, theories, key variables and phenomena, and its methods and history (Randolph, 2009). Another purpose is identifying the research gap and providing a theoretical framework for relating new findings to previous findings in the discussion section (Randolph, 2009). The author conducted the literature review under the framework from vom Brocke et al. (2009). (See Figure 3.1).



Source: vom Brocke et al.(2009); the author

Figure 3.1 Framework for literature review

In the first stage of the definition of review scope, mainly following the taxonomy of literature review with Cooper (1988). The literature review is mainly research outcomesorientated to identify the lack of information with research outcomes for establishing a justifiable need, as well as deal with the methodological flaws that might affect an outcome (Randolph, 2009) and further critically analyse the literature (Randolph, 2009). Additionally, the review will be conducted in espousal of the position. For the coverage of the literature, consider an exhaustive review with selective citation (Randolph, 2009) since UAV adoption in EM is an emerging topic recently. The sources consist of pertinent English and Chinese scholarly journals that systematically document researched knowledge, covering the period from 2015 to 2025, as the UVA represents an emerging innovative technique for compiling cutting-edge research. The review will subsequently be organised in a historical and methodological framework for specialised scholars and general audiences.

In the second stage of the conceptualisation of the core term in the topic around the keywords used for the subsequent keyword search are as follows: " wildfire/forest fire/land fire/bushfire", " emergency management", "natural hazard emergency management", "wildfire management in China", "UAVs/Drones", "UAVs/Drones in wildfire management", "UAVs/Drones in wildfire management in Sichuan", application/adoption, challenges, and opportunities.

The third stage is the forward search process (vom Brocke et al., 2009), which involves the database search with KU Leuven Limo and CNKI, while applying keyword search as mentioned and only peer-reviewed journals included, then evaluating the literature with the title, abstract, and the full text.

After collecting sufficient literature, moving forward to analysis and synthesis of the literature as suggested by Randolph (2009) that highlights and identifies the meaningful statements with a spreadsheet, then categorising these statements for interpretation and paraphrasing into groups, and ultimately developing a comprehensive description of the core experiences of primary researchers regarding the theme of UAV integration with WEM. Finally, the research agenda is derived from the synthesis of the research gap and the theoretical framework..

3.1 Wildfire emergency management study foundations

3.1.1 WEM elements and methods

Pre-wildfire: risk reduction and preparedness

The pre-fire phase focuses on minimising fire occurrences through risk reduction and pre-response measures (Huidobro, Giessen & Burns, 2024). Traditional wildfire mitigation strategies, including shade firebreaks, controlled burning, and afforestation, have been widely used to manage high-risk areas for fire (Huidobro, Giessen & Burns, 2024). Shaded firebreaks can reduce surface fuel loads, creating buffers to facilitate fire suppression (Wang et al., 2021). The use of fire itself for land management through prescribed burning has proven effective in reducing wildfire risks and mitigation costs (Calkin, Thompson, & Finney, 2015). Importantly, the challenge remains in determining where, when, and how much to burn (Li et al., 2023); in other words, it is about identifying the appropriate location, timing, and quantities for burning. While afforestation projects have been combined to enhance ecological resilience for fire control, they have also increased fuel loads, inadvertently raising wildfire risks in the long term (Zong, Tian & Fang, 2022; Hayes, 2021).

In contrast, modern approaches leverage predictive analytics and remote sensing (RS) technologies to improve wildfire prevention and preparedness. AI-driven models analyse historical fire data, climate patterns, and vegetation conditions to forecast fire risks and optimise fuel management strategies (Ermagun et al., 2025). Furthermore, RS technologies such as satellite-based thermal imaging and Light Detection and Ranging (LiDAR) technology for land surface scanning provide critical data for early fire detection and fuel load assessment (Christopher & Thompson, 2016). Additionally, UAVs offer real-time fire surveillance, enabling rapid response planning and resource allocation for both prescribed burns and afforestation (Christopher & Thompson, 2016).

During-wildfire: suppression and response

Control, coordination, and resource deployment are the main priorities of the response to a fire (Huidobro, Giessen & Burns, 2024). Decisions are mostly based on dispatch plans, and modern firefighting tactics prioritise quick control using firefighters, aerial firefighting, and ground fire vehicles (Martell, 2015). However, during wildfires, Wu &

Lyu (2024) emphasised the necessity of public involvement in emergency response procedures.

Nevertheless, technology-driven methods can boost situational awareness and decision-making during fires. For example, real-time data from remote sensing platforms, drones, and geospatial tools enable wildfire managers to assess fire behaviour and dynamically adjust response strategies (Christopher & Thompson, 2016). Combined with decision support systems, such as the Wildfire Decision Support System (WFDSS) in the United States and the European Forest Fire Information System (EFFIS), predictive models are combined with geospatial data to optimise suppression efforts. Greece's AEGIS system further enhances these capabilities, improving fire spread prediction and response coordination (Christopher & Thompson, 2016).

Despite these technological advancements, implementation challenges remain in data interoperability, regulatory constraints, and resistance to adopting new technologies (Tymstra et al., 2019; Ermagun et al., 2025). Overcoming these barriers will require ongoing collaboration among research, government, and private technology stakeholders, as well as coordination and organisational adjustments within emergency management agencies.

Post-wildfire: recovery and adaptation

The post-fire phase involves monitoring, rehabilitation, and long-term risk reduction (Huidobro, Giessen, & Burns, 2024). Following the official extinguishment of a wildfire via "cold trailing", which involves monitoring the affected area for potential re-ignition (NWCG, 2016), recovery efforts subsequently concentrate on ecological restoration, socio-economic impact assessments, and policy adaptation (Huidobro, Giessen, & Burns, 2024). Regardless, a key challenge in post-fire management is the reinforcement of self-perpetuating fire control measures (Son et al., 2020) because resilient post-wildfire governance requires adaptive decision-making, collective sensemaking, and improved coordination between agencies and communities (Son et al., 2020). Integrating lessons from past fire events into future preparedness strategies, along with leveraging technological advancements, which is essential for establishing long-term resilience against wildfires (Huidobro, Giessen, & Burns, 2024).

3.1.2 Challenges in wildfire emergency management

WEM has experienced considerable evolution influenced by technological advancements, socio-political dynamics, and changing fire regimes. Historically, fire suppression was the dominant strategy, driven by the assumption that minimising fire occurrences would reduce environmental and economic damage (Calkin, Thompson, & Finney, 2015). However, this approach has led to the "wildfire paradox", where aggressive suppression efforts have inadvertently increased wildfire risks by allowing fuel loads to accumulate, leading to larger, more severe fires (Calkin, Thompson, & Finney, 2015). This paradox highlights the necessity of integrating suppression with proactive mitigation strategies that emphasise ecological resilience and risk reduction (Son, Sasangohar, Neville, Peres, & Moon, 2020). However, political pressures and public expectations reinforce suppression-based policies and often relegate alternative strategies such as prescribed burning and fuel management to a secondary priority (Tymstra et al., 2019).

The economic dimension further complicates WEM because resource allocation is often guided by cost-effectiveness principles, as well as funding remains insufficient to support an integrated and innovative approach (Tymstra et al., 2019). The prevailing strategy assumes that the final resource assigned should equal the expected reduction in net loss (Calkin, Thompson, & Finney, 2015). Thus, overcoming entrenched paradigms necessitates institutional and cultural shifts within wildfire management agencies, as well as increased public acceptance of adaptive fire management strategies (Calkin, Thompson & Finney, 2015).

The complexity and uncertainty of wildfire behaviour, along with incomplete information, complicate the implementation of WEM (Zhou et al., 2018). Agencies have varying responsibilities and risk assessment frameworks, often prioritising technology-led solutions such as risk mapping and fire suppression infrastructure (Tedim et al., 2021). While these tools are essential, achieving long-term wildfire risk reduction requires a more holistic perspective that combines community-based adaptation, socio-ecological resilience, and landscape-scale fire management (Tedim et al., 2021). Coordinating efforts across local, state, and national levels is essential for aligning resources, responsibilities, and actions to enhance the effectiveness of WEM, rather than depending exclusively on technical experts (Ermagun et al., 2025).

Summary

Considering the constraints of conventional wildfire suppression and the difficulties associated with technology integration, a balanced and flexible technology-driven WEM strategy is essential. Successful wildfire management requires the integration of ecological principles, technological innovation, and governance reforms. While predictive analytics, drones, and RS technologies offer promising advances, their effectiveness in implementation depends on institutional ability, financial resources, regulatory frameworks, and intersectoral collaboration.

Moving forward, it is essential to transition to proactive and technology-driven wildfire management. This entails enhancing early warning systems, advocating adaptive fuel management solutions, and establishing robust governance frameworks capable of dynamically addressing escalating fire threats. By tackling structural and operational impediments to innovation, wildfire control systems can evolve towards more sustainable and effective methods to alleviate the escalating severity of wildfires resulting from climate change and anthropogenic factors.

3.2 UAVs in emergency management

3.2.1 Evolution of UAV technology

UAVs have evolved significantly from their initial military applications to becoming essential instruments in various civilian and emergency management domains (Tang & Shao, 2015). However, the increasing frequency and intensity of wildfires globally have accelerated research on UAV applications in wildfire events. Modern wildfire detection and management rely on methods such as satellite imagery, wireless sensor networks (WSNs) (Chen et al., 2024), watchtowers, and human patrols (Partheepan, Sanati, & Hassan, 2022). Satellites exhibit limited manoeuvrability and flexibility, which hinders effective monitoring of rapidly changing wildfire events. In contrast, WSNs face challenges related to static installation and battery recharging in remote areas; however, they remain valuable during wildfires.

These methods yield valuable data; however, they often face challenges such as delayed detection, elevated operational costs, and dependence on manual intervention (Partheepan, Sanati, & Hassan, 2022). Consequently, these conventional limitations highlight the innovative, real-time, and scalable solution in WEM (Chen et al., 2024), contributing to the current trend of UAV deployment in WEM.

Meanwhile, UAV technology provides an economical and efficient alternative by enhancing wildfire detection, monitoring, and response (Boroujeni et al., 2024). For instance, equipped with thermal imaging cameras, LiDAR, meteorological sensors, and real-time data transmission capabilities, UAVs can operate in hazardous environments without risking human personnel to danger (Boroujeni et al., 2024). In addition, compared to traditional aircraft, UAVs offer enhanced operational flexibility, enabling access to high-risk zones, low-visibility areas, and distant forested regions effortlessly (Bailon-Ruiz & Lacroix, 2020). Furthermore, UAVs can be integrated into multi-layered disaster response frameworks, working alongside ground-based sensors and satellite monitoring systems to enhance wildfire management techniques (Khan, Gupta, & Gupta, 2022).

3.2.2 Role of UAVs in WEM

3. Detection & monitoring

UAVs have emerged as a vital tool for wildfire detection and monitoring, providing significant advantages over traditional methods such as ground-based sensors and satellite imagery (Afghah et al., 2019; Bailon-Ruiz, Bit-Monnot, & Lacroix, 2022). Importantly, equipped with high-resolution optical, infrared, and multispectral sensors, UAVs facilitate real-time surveillance of fire-prone areas, allowing for early detection of ignition points and delivering critical data on fire spread dynamics (Partheepan, Sanati, & Hassan, 2022). In contrast to conventional smoke detectors and thermal sensors, which often fail to provide precise fire location and intensity measurements, UAVs are capable of accurately evaluating fire size, direction, and propagation speed through onboard data processing and transmission to ground stations for subsequent analysis and formulation of effective suppression strategies. (Bailon-Ruiz, Bit-Monnot, & Lacroix, 2022; Partheepan, Sanati, & Hassan, 2022). Additionally, computer vision algorithms and image processing techniques improve UAV-based fire detection through the analysis of multiple fire indicators, such as heat signatures, smoke plumes, and chemical by-products. Moreover, high-sensitivity infrared cameras further improve detection capabilities in low-visibility conditions, including nighttime scenarios or when flames are obscured by dense vegetation or smoke (Partheepan, Sanati, & Hassan, 2022). Besides, AI-driven systems, such as the BOSQUE fire detection model, have been developed to filter false alarms and optimise detection accuracy, illustrating the capability of UAVs as a reliable and effective component of wildfire emergency management (Kinaneva et al., 2019).

4. Suppression & containment

UAVs significantly contribute to wildfire suppression and containment by enhancing situational awareness, optimizing resource allocation, and supporting direct intervention efforts. Since UAVs equipped with onboard cameras and navigation sensors facilitate search and rescue operations by swiftly identifying and locating potential victims in disaster-affected areas, thereby reducing response time and operational costs while increasing the probability of saving lives (Partheepan, Sanati, & Hassan, 2022). Beyond that, Momeni and Al-e-Hashem (2024) proposed that UAVs can collaborate with WSNs to monitor fire dynamics and environmental conditions, enabling precise resource deployment for suppression efforts. Additionally, UAV-based wireless networks enhance fire data collection through cluster head election techniques, which ensure robust and efficient data transmission (Wang, Lee, & Ahn, 2018). Moreover, UAV-assisted wildfire monitoring functions, integrating thermal and RGB cameras with wireless communication to conduct real-time fire tracking, intensity inspections, and resource coordination (Liu et al., 2023). Brust & Strimbu (2015) came up with a drone swarms model for high-quality forest mapping and adaptive fire containment strategies, demonstrating their potential in large-scale wildfire suppression efforts. But (Ebrahimi, et al. (2024) propose a cooperative search and coverage for multiple drones in uncertain environments for wildfire emergency management. Moreover, emerging UAV systems are being developed to carry fire-extinguishing payloads, providing a proactive approach to suppression, which in contrast to conventional monitoring drones that primarily rely on passive data observation (Momeni & Al-e-Hashem, 2024). This evolution underscores the growing significance of UAVs in detecting and tracking wildfires as well as actively mitigating their effects through targeted suppression operations.

5. Post-fire recovery & assessment

UAVs have proven to be an efficient instrument for assessing post-wildfire conditions and monitoring vegetation recovery (Talucci et al., 2019), especially in areas where field data collection is difficult and satellite imagery is limited by cloud cover and revisit intervals. UAVs equipped with multispectral sensors enable high-resolution mapping of burn severity, vegetation regeneration, and landscape changes with greater accuracy and shorter data acquisition times compared to traditional satellite-based methods (Samiappan et al., 2019; Talucci et al., 2019). Additionally, UAV photogrammetry facilitates the early detection of post-fire hazards, including landslides, by capturing detailed soil and slope deformations in fire-affected landscapes (Deligiannakis et al., 2021).

Meanwhile, multi-temporal UAV imagery, when integrated with digital surface models, improves post-fire classification accuracy and enables precise assessment of ecosystem recovery dynamics at both landscape and plot levels (Qi et al., 2022; Van Blerk et al., 2022). UAVs do not completely substitute for ground-based measurements; however, they considerably improve the assessment of burn severity and vegetation regrowth patterns, especially when combined with conventional field surveys (Van Blerk et al., 2022). Yet, their ability to provide on-demand, high-frequency data collection improves disaster response and long-term ecological monitoring, addressing deficiencies in conventional remote sensing methods (Aicardi et al., 2016; McKenna et al., 2017). Therefore, the rapid and cost-effective deployment of UAVs makes them a promising instrument for post-fire environmental monitoring in vulnerable ecosystems. But the application for post-fire recovery requires additional development (Deligiannakis et al., 2021).

3.2.3 Challenges of UAVs adoption in WEM

The increasing integration of UAVs in wildfire emergency management faces multiple technical, operational, and regulatory challenges that impede their broader implementation. The challenges affect UAV performance, deployment efficiency, and adherence to legal frameworks.

1. Technical challenges

Researchers primarily examined the technical limitations related to battery capacity, payload capacity, data transmission, and weather conditions.

The primary technical limitation of UAVs in WEM is their limited battery capacity, which restricts flight endurance and operational range. UAVs utilise onboard batteries to energise their propulsion systems, data processing units, and communication modules. However, small UAVs possess constrained payload capacity, which makes it difficult to integrate larger batteries (Lou et al., 2015). This limitation hinders UAVs from conducting prolonged surveillance of wildfire-prone areas. Research is ongoing to develop energy-efficient UAV designs, advanced battery technologies, and wireless power transfer systems to improve endurance (Partheepan, Sanati, & Hassan, 2022). The second limitation is payload capacity, which is a critical factor influencing UAV functionality in wildfire monitoring. For instance, mini-UAVs can only carry limited payloads, which restricts their ability to support high-resolution multispectral and hyperspectral sensors for fire detection (Lou et al., 2015). Thirdly, the issues on the effective wildfire data analysis model since UAVs generate significant quantities of data that require real-time processing for effective decision-making. Whereas as Khan et al. (2023) mentioned that lack of extensive wildfire datasets for training models; most models are developed using smaller wildfire events, and may not adequately represent extreme wildfire contexts. Therefore, the challenge involves the development of AI-driven analytics, cloud-based data storage solutions, and enhanced onboard computing capabilities to handle large datasets efficiently for different scale of wildfire (Boroujeni et al., 2024), while Khan et al. (2023) also ask for developing broader models that can integrate different stages of wildfire management effectively.

Besides, the weather conditions, such as strong winds, smoke, rain, clouds and extreme temperatures, can impair UAV navigation, reduce sensor accuracy, and increase the likelihood of mission failure (Partheepan, Sanati, & Hassan, 2022). Additionally, smoke-induced low visibility can interfere with UAV-based imaging systems, complicating the detection of fire spread patterns. Moreover, the absence and unstable GPS signal also worsen the precision location of the targeted hotpot (Partheepan, Sanati, & Hassan, 2022). Advancements in weather-resistant UAV designs, adaptive flight stabilisation algorithms, and autonomous navigation systems are essential to address these risks (Luo et al., 2019).

2. Organisational challenges

Effective UAV deployment in wildfire management requires optimized finance and human resource allocation, reform capability, strategic UAV placement, and real-time coordination within the emergency response agency.

The primary concern is the insufficient financial support necessary to implement and integrate the vision of an innovative technique to wildfire management (Tymstra et al., 2019; Khan et al., 2023). The manifestation of self-reinforcing and costly behaviour within the WEM organisation is constrained not only by the financial interests of established firefighting organisations in preserving existing policies but also by managerial incentive structures that prioritise short-term results for credit (Calkin, Thompson, & Finney, 2015). Consequently, the organisation exhibits the capacity for structural reform, which is essential for strategic UAV placement and cross-sector coordination.

In addition, UAVs often operate in remote wildfire-affected areas, where establishing communication links and managing UAV fleets can be challenging (Khan, Gupta, & Gupta, 2022) so that optimising UAV trajectory planning, energy-efficient flight scheduling, and seamless integration with existing disaster management systems is essential for enhancing UAV effectiveness in WEM (Khan, Gupta, & Gupta, 2022).

Further, effective integration of UAVs into wildfire emergency response relies on expertise of operators and interdisciplinary collaboration among emergency response agencies, meteorologists, and UAV specialists. However, training programs and standardised operating procedures for UAV deployment in WEM remain underdeveloped in many regions (Khan, Gupta, & Gupta, 2022). Therefore, suggested by Luo et al. (2019) that the establishment of certified UAV training programs, simulation-based scenario training, and automated UAV operation protocols can improve human-technology collaboration in wildfire response.

3. Regulatory challenges

UAV operations are regulated by national and international airspace laws, which differ considerably among various countries. Strict airspace restrictions, altitude limits, and necessary operational approval can impede UAV deployment in wildfire emergencies (Khan, Gupta, & Gupta, 2022). Certain regions prohibit UAV flights in protected natural reserves or adjacent to populated areas, thereby further constraining UAV accessibility in wildfire-prone areas. The establishment of harmonised international regulations and adaptable emergency-use UAV policies can enhance the efficiency of UAV deployment in WEM (Luo et al., 2019). On the other hand, regulations encompass pilot licensing, UAV registration, and special flight permissions, particularly in commercial and scientific contexts (Khan, Gupta, & Gupta, 2022). Although these measures improve safety and accountability, they may impede rapid emergency UAV deployment. Simplifying regulatory frameworks for emergency UAV use and establishing pre-approved UAV flight corridors could accelerate UAV deployment in wildfire scenarios (Luo et al., 2019).

Additionally, the deployment of UAVs for wildfire monitoring presents issues related to privacy violations and data security.UAV-mounted cameras and sensors may inadvertently record private properties, individuals, and restricted areas, resulting in potential legal and ethical concerns (Khan, Gupta, & Gupta, 2022). To address these concerns, it is essential to implement transparent data governance policies, establish privacy-preserving UAV operation protocols, and promote public awareness initiatives that balance emergency response requirements with privacy rights (Luo et al., 2019).

In conclusion, despite UAVs provide substantial benefits in WEM, their technical, operational, and regulatory challenges also hinder broader adoption. Overcoming these barriers requires progress in UAV technology, optimised operational strategies, organisational reform and adaptive regulatory frameworks.

3.3 Methodologies in UAV-WEM research

Research on UAV applications in WEM have predominantly utilised simulation models, field data collection, and systematic literature reviews. On the one hand, simulation-based studies (Lambert et al., 2024; Van Blerk et al., 2022) have been instrumental in optimising UAV deployment strategies, predicting fire spread, and evaluating UAV effectiveness across various wildfire scenarios. Although these models provide controlled settings for experimentation, their dependence on predefined parameters limits real-world applicability, particularly in the context of complex and unpredictable wildfire conditions. Meanwhile, field studies (Aicardi et al., 2016; McKenna et al., 2017) offer empirical validation through the deployment of UAVs in active wildfire zones, facilitating the collection of real-time environmental data, and evaluating sensor performance. Nevertheless, these studies encounter obstacles related to cost, logistical constraints, and scalability, making it difficult to generalise findings across diverse wildfire conditions. On the other hand, systematic literature reviews (Partheepan, Sanati, & Hassan, 2022; Khan, Gupta, & Gupta, 2022) have synthesised existing research trends, highlighting technological advancements and gaps in UAV-WEM applications. Although these reviews are comprehensive, they frequently rely on secondary data, which restricts their ability to capture emerging challenges in UAV integration in the current WEM applications.

Ultimately, it is essential to obtain the stakeholders' insights from the technical, WEM organisation, and regulatory dimensions for real-world applications throughout the life cycle of wildfire events, so the TOE framework and H-EMLC theory could be implemented as the foundation for further qualitative data collection and analysis method in bridging the research gap.

3.4 Research gap

This This section presents the research gap after the literature synthesis (Müller-Bloch & Kranz, 2015). This study identifies a methodological gap and a knowledge gap in the emerging research on UAVs within the WEM field.

Firstly, existing research has predominantly focused on quantitative technical performance metric, simulation-driven optimisation, and systematic review, while neglecting the human and organizational factors that influence UAV adoption in real-world wildfire management. Allouch et al. (2019) highlight the necessity of combining qualitative assessments with quantitative risk analysis to attain a thorough understanding of the challenges and opportunities associated with UAV deployment. Hence, this study addresses the methodological gap regarding the rapid advancements in UAV technology and its increasing role in disaster management by adopting a qualitative approach to examine the implementation, and integration of UAVs into WEM systems.

Secondly, there are productive research focuses on assessing the strengths and limitations of UAVs in WEM (Akhloufi et al., 2021; Keerthinathan et al., 2023; Sun et al., 2023; Partheepan et al., 2022). To enhance the effectiveness and overcome technical limitations, prior researchers can be divided into three trends: (1)The integration of UAVs with various technologies, such as AI (Akhloufi et al., 2021; Keerthinathan et al., 2023; Boroujeni et al.,2024); unmanned systems like unmanned ground vehicles (Sun et al., 2023); and deep learning-based risk assessment (Peng et al., 2023; Xie et al., 2021); (2) Sun et al (2023) propose enhancing UAVs' endurance, mobility, and adaptability to complex environments. This enhancement is essential for supporting broader extensive phases in WEM, including planning and post-fire recovery (Boroujeni et al., 2024); (3) Partheepan, Sanati, & Hassan (2022) propose to integrate UAVs with whole EM systems, focussing interaction with the organisations, as well as relates to regulatory challenges and improving the cost-effectiveness of UAV systems (Boroujeni et al., 2024).

Although these studies provide valuable insights into maximising the technological capabilities of UAVs, they often neglect the organisational and environmental factors that influence UAV adoption in practical WEM systems. From an organizational standpoint, research has emphasized multi-organizational collaboration and decision-support systems for WEM (Zhou et al., 2018). Nonetheless, the challenges present in the coordination within and between organisations, including coordination among local agencies, responders, and private UAV service providers remain insufficiently studied. Research has examined legal and governance aspects of WEM (Schinko et al., 2023) from an environmental and regulatory standpoint, as well as the function of social media as an additional data source (Luna & Pennock, 2018). However, research has not sufficiently explored the influence of external regulatory constraints and evolving policy frameworks that impact UAV deployment in technical default and WEM organisation adoption. Besides, the function of UAVs in China's integrated WEM system has also not been systematically assessed.

Accordingly, this research incorporates stakeholder insights to address the knowledge gap between technological feasibility and practical implementation from an organisational and environmental lens, ensuring that UAV-driven innovations align with the operational needs of WEM.

In short, given these findings, this study seeks to bridge these methodological and knowledge gaps by evaluating the integration of UAVs into China's overall WEM system by examining how UAVs fit within WEM response workflows, policy frameworks, and inter-organisational coordination. It draws upon the TOE framework and H-EMLC theory to systematically assess, which offers an in-depth understanding of UAV adoption in China's WEM, moving beyond previous technical performance to evaluate the implementation opportunities and challenges within the Chinese context for effective UAV integration.

3.5 Theoretical frameworks

Building on the literature review and prior studies concerning WEM and innovative technology adoption, this section presents the theoretical foundations guiding this study. Two interrelated frameworks are adopted: the Technology–Organization–Environment (TOE) framework and the Hazard Emergency Management Life Cycle (H-EMLC). These frameworks are selected for their capacity to support a comprehensive, multi-level analysis of the integration of UAVs into the WEM system in Sichuan Province, China. Specifically, the TOE framework allows a structural and contextual analysis of UAV adoption through examining technological capabilities, organisational readiness, and environmental conditions. Meanwhile, the H-EMLC theory provides a temporal lens for locating the changing function of UAVs across different wildfire management phases. How they address the research gap can see Table 3.1. Together, these frameworks address gaps in existing literature, which often neglect the interaction between systemic barriers and lifecycle-specific applications. In this study, they provide a deductive foundation for guiding qualitative data collection and support inductive thematic reasoning during analysis.

Table 3.1 Frameworks role in addressing research gap

Framework	Purpose in this study	Literature gap to address
TOE	• Analyse structural and contextual adoption factors (technology, organisation, environment)	• Lack of integrated analysis beyond technical performance
H-EMLC	• Explore UAV roles across wildfire phases (preparedness/prevention, response, recovery)	• Underexplored role of UAVs in full wildfire life cycle integration

3.5.1 Technology-Organisation-Environment (TOE) framework

The Technology–Organization–Environment (TOE) framework, originally developed by Tornatzky and Fleischer (1990), provides a model to understand innovation adoption by categorizing influencing factors into three domains: the technological, organizational, and environmental context, could influence innovation, adoption, and scalability in a broad spectrum of innovative technology (Baker, 2011):

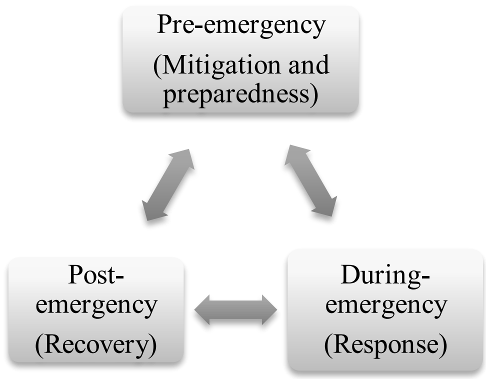
(1) Technological context: the characteristics of the UAVs themselves, including characteristics such as performance, range, endurance, payload, and data-processing

capabilities and availability; (2) Organizational context: formal and informal internal institutional attributes such as coordination capacity, administrative structure, financial resources, and communication process, as well as organisation size; (3) Environmental context: external influences such as government regulations such as airspace control, privacy protection; technology support infrastructures; industry characteristics, etc.

In this research, the TOE framework is applied to address the first and second research sub-questions, which explore the technical strengths and limitations of UAVs and the organizational and environmental opportunities and constraints for their integration into China's WEM systems. The TOE framework is general enough to apply across a wide range of technologies, while being specific enough to guide empirical inquiry (Baker, 2011, p. 241). Therefore, the strengths of the TOE as a "generic" theory with inherent adaptability and flexibility for varying the factors or measures index for latest technology innovation adoption in different organisation context as well as the stable evolution of the theory, make it appropriate to align with other theories in empirical research (Baker, 2011). As Baker (2011) notes, "the TOE model has been shown to be useful in the investigation of a wide range of innovations and contexts" and remains adaptable to new domains and evolving technologies. The TOE framework is widely accepted in information systems and public sector innovation research due to its analytical flexibility and empirical robustness. Its adaptability is particularly suitable for studies examining novel technologies such as UAVs in the public sector agencies for WEM with systematically capturing the interaction between technological capabilities, organisational dynamics and environmental factors.

3.5.2 Hazard emergency management life cycle (H-EMLC) theory

The Hazard Emergency Management Life Cycle (H-EMLC) theory divides emergency management activities into sequential phases. While previous researchers have employed various division methods for the wildfire management. Pursiainen (2017) divided into six phases: risk assessment, prevention, preparedness, response, recovery, and learning. The '4R' theory is also commonly used, which encompasses reduction, readiness, response, and recovery (Tang et al., 2022; Mustari et al., 2024). While various models exist, this study adopts the three-phase structure widely used comprising pre-emergency (prevention and preparedness), during-emergency (response), and post-emergency (recovery) (Chen et al., 2019). This framework is illustrated in Figure 3.2.



Source: Chen et al.(2019)

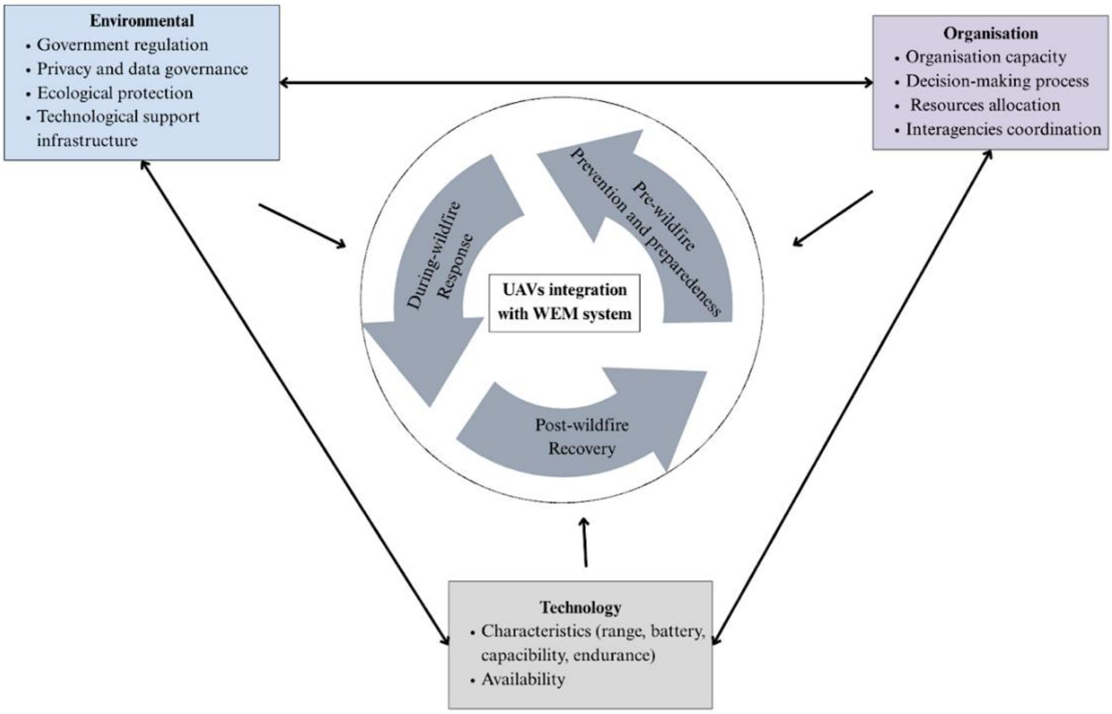
Figure 3.2 Hazard emergency management life cycle (H-EMLC) theory

This temporal classification is commonly applied in both academic and policy-oriented research to analyze strategic planning and operational responses in emergency contexts. Although scholarly debate exists regarding the segmentation of WEM activities, this tripartite structure offers clarity and practical relevance for analyzing how UAVs contribute across different stages of the emergency cycle. Accordingly, this framework supports the third research sub-question, which seeks to assess how UAVs enhance emergency management capabilities throughout each life cycle stage.

3.5.3 Framework overview

The combination of the H-EMLC and TOE frameworks enables a multi-dimensional approach to this research. The H-EMLC offers a temporal and functional structure for assessing UAV roles across wildfire management phases, whereas the TOE framework provides an explanatory structure for understanding the technological, institutional, and environmental factors influencing UAV adoption.

Although each framework possesses inherent limitations. The H-EMLC may oversimplify overlaps between emergency phases, while the TOE may not encompass all influential elements, their complementary strengths serve to mitigate these gaps. As emphasised by Kivunja (2018), a robust theoretical framework functions as a “coat hanger” that organises and guides empirical analysis. Grant and Osanloo (2014) further assert that theoretical frameworks should be explicitly aligned with the research questions, problem, and methodology. The selection of H-EMLC and TOE fulfills these criteria by offering both conceptual clarity and analytical depth.



Source: the author

Figure 3.3 Theoretical framework

Ultimately, the research methodologies developed in this study integrate the H-EMLC phases with the TOE dimensions to frame the data collection and data analysis for addressing the research question. As illustrated in Figure 3.3, the model visualises how UAV roles are mapped across the wildfire management life cycle, while also identifying the technological, organisational, and environmental factors that influence their integration. This model enables a structured, theory-based assessment of UAV adoption and supports the research objective of generating practical and policy-relevant insights for wildfire management in the Chinese context.

3.6 Conclusion and research implications

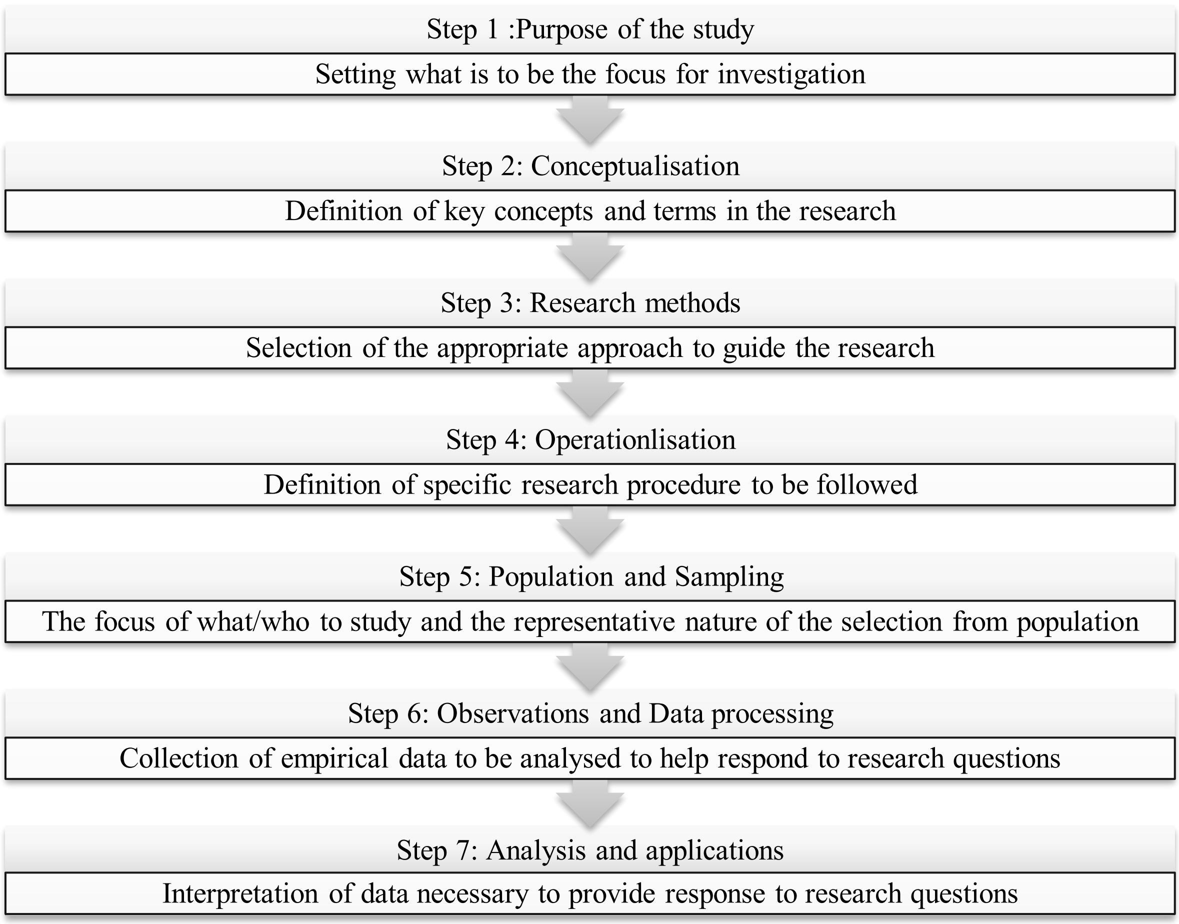
This literature review has systematically analysed the research on the integration of UAVs within WEM and identifies knowledge and methodological research gaps, emphasising its utilisation across various hazard management phases: pre-wildfire, during-wildfire, and post-wildfire and the challenges encountered for wider adoption. It recognised significant technology innovations and uses, including risk prediction, real-time monitoring, and post-fire evaluations. Nevertheless, the literature remains insufficient regarding the complex interactions between UAV technologies and the operational and policy frameworks in emergency management. The integration of UAVs into existing wildfire management workflows and the impact of organisational structures, communication practices, and regulatory environments on their effective use are particularly underexplored, which calls for further qualitative insights from the stakeholders from real-world implementation.

Therefore, this study utilises the TOE framework combined with the H-EMLC theory to address the identified research gaps comprehensively. Firstly, the TOE framework provides a foundation to evaluate multidimensional factors influencing UAV adoption, whereas the H-EMLC contextualises UAV functionality within the specific stages of wildfire management. Together, these frameworks enable a holistic exploration of opportunities and challenges, linking technological potential with practical application.

In conclusion, the implications of this research extend both theoretically and practically. Theoretically, this study enriches the existing discourse by integrating organisational and environmental dimensions into UAV adoption research, which has been dominated by technological factors. Practically, the insights derived from this research are intended to assist policymakers, emergency management agencies, and UAV developers in effectively addressing the challenges of UAV integration, thereby enhancing wildfire response capabilities and operational resilience in regions susceptible to wildfires.

4 Research Design

Generally, the research process consists of three primary stages: posing a question for examination, collecting data to answer the question, and presenting an answer to the question (Abutabenjeh & Jaradat, 2018). Therefore, this chapter outlines the research design plan, research methodology, with data collection and analysis methods to explore the integration of UAVs into China's WEM system, focusing on Sichuan Province, seeking to assess the technological, organizational, and environmental challenges and opportunities across whole phases of hazard emergency management.



Source: Babbie (2004)

Figure 4.1 Research design map

Research design framework here is the comprehensive plan for data collection and data analysis aiming at answering the research questions and providing a solid base for the whole research. The author chose the best-known works of Earl R. Babbie (2004) as guidance to outline the blueprint, which states that "designing a study involves specifying exactly who or what is to be studied, when, how, and for what purpose" Accordingly, Babbie (2004) defined seven steps for designing a research project (see Figure 4.1) and each step will be explained with more details in this chapter.

4.1 Defining the purpose of the project

Scientific research projects are categorised into three types: exploratory, descriptive, and explanatory (Bhattacherjee, 2012). Exploratory research is employed in novel or insufficiently examined domains to evaluate the extent of a phenomenon, produce preliminary insights, or assess the viability of additional investigation (Bhattacherjee, 2012). Descriptive research systematically documents and analyses characteristics or patterns through scientific methods to ensure accuracy and reliability (Bhattacherjee, 2012). While explanatory research aims to identify causal relationships by examining the reasons and mechanisms behind a phenomenon, linking observed factors to outcomes (Bhattacherjee, 2012). These research approaches offer a systematic framework for transitioning from the comprehension of a phenomenon to elucidating its fundamental mechanisms.

This research belongs to an exploratory research project because the objective is to assess the scope of UAVs integration with WEM in China, aiming to identify its challenges and opportunities while fulfill the knowledge and methodological research gap in implementing UAVs within WEM systems throughout the wildfire management life cycle from technological, organisational, and environmental dimensions.

4.2 Conceptualisation

After defining the research objective and anticipated outcomes. This stage can process to conceptualisation, which means specifying the particular terminology in this research (Abutabenjeh & Jaradat, 2018), which can refer to Chapter 2, including: wildfire, wildfire management, wildfire management system, UAVs, etc. Conceptualisation is important to define the concrete and precise terms within the social science framework (Abutabenjeh & Jaradat, 2018), not only for the author to avoid misunderstanding the fundamental concept and minimize the risk of distortion and imprecision in the subsequent research stages, but also to make the audience better comprehend this theme (Abutabenjeh & Jaradat, 2018). Importantly, it constrains the literature review search scope.

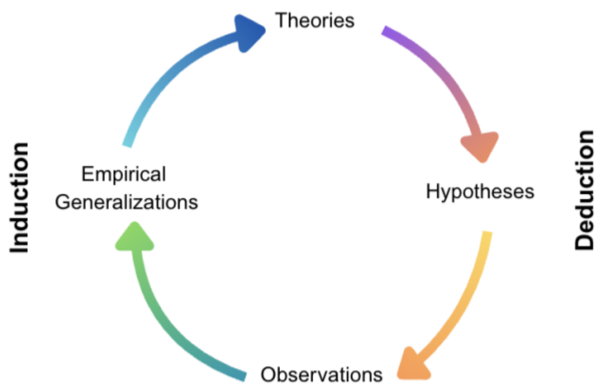
4.2.1 Choice of research method

In this stage, the author explores the various observational techniques or research methods available, such as experiments, survey research, qualitative field research, unobtrusive research, and evaluation research (Abutabenjeh & Jaradat, 2018). Each research method has its strengths and weaknesses (Abutabenjeh & Jaradat, 2018). For example, Babbie (2004) noted that the best study design uses more than one research method, taking advantage of their different strengths.

4.2.2 Research forms

Given that theories and observations are the two pillars of science, scientific research operates at two levels: a theoretical level and an empirical level (Bhattacherjee, 2012). Both are essential components for research.

On the one hand, the theoretical level is concerned with developing abstract concepts about a natural or social phenomenon and relationships between those concepts, which means to build "theories" (Bhattacherjee, 2012). On the other hand, the empirical level is concerned with testing the theoretical concepts and relationships to see how well they reflect observations of reality, to ultimately build better theories (Bhattacherjee, 2012). Over time, a theory becomes more and more refined (i.e., fits the observed reality better), and the science gains maturity (Bhattacherjee, 2012).



Source: Bhattacherjee (2012)

Figure 4.2 Research form

Therefore, scientific inquiry has two possible forms: inductive or deductive (Bhattacherjee, 2012), which can be seen in *Figure 4.2*. In inductive research, the goal is to infer theoretical concepts and patterns from observed data (Bhattacherjee, 2012). Deductive research is about testing concepts and patterns known from theory using new empirical data (Bhattacherjee, 2012). In short, inductive research is about theory-building research, and deductive research is theory-testing research (Bhattacherjee, 2012).

Since this research is designed to investigate the challenges and opportunities in large-scale technology adoption for effectively coping with the threats of wildfire to fill the research gap in assessing the technological, organizational, and environmental challenges and opportunities across all phases of WEM, inductive reasoning will be applied as the primary method. But it is also need to make it clear that this research used the existing theoretical framework as the foundation and structure to collect and analyse the data, therefore, this part belongs to deductive.

4.2.3 Research method

This research adopts an exploratory research design to investigate a complex and evolving phenomenon of integration of UAVs into WEM systems in China, with a particular focus on Sichuan Province. According to Bhattacherjee (2012), exploratory research is particularly suitable for domains with insufficient theoretical frameworks or when the objective is to identify patterns, relationships, and contextual insights instead of testing established hypotheses. The case study method is identified as the most appropriate technique for exploratory research among traditional methods such as case research, experimental studies, and action research. The rationale is outlined below:

Experimental research is mainly used in explanatory studies to determine causal relationships under controlled environments and is not ideal for studies exploring context-dependent social, organisational, and technological dynamics, as demonstrated in this case (Bhattacherjee, 2012). Action research serves as a valuable method for assessing interventions and promoting organizational change, emphasizing theory testing and practical application over theory development. It generally encompasses iterative cycles of change and evaluation, which extend beyond the scope of this thesis.

In contrast, case research, also called a case study, is characterised as a thorough and contextually rich examination of a phenomenon within its actual environment, aligning closely with the objectives of this study. According to Bhattacherjee (2012), case research is particularly useful for theory development in emerging fields, as it reveals new concepts and relationships that may not be fully understood or anticipated beforehand. This is essential for the current study, considering the dynamic integration of UAVs in

WEM systems, which encompasses a combination of technical, organisational, and regulatory elements situated within particular institutional and geographic contexts.

Moreover, several methodological advantages reinforce the selection of the case study approach:

Firstly, case research facilitates inductive reasoning, which aids in identifying pertinent variables, patterns, and relationships that enhance conceptual development in under-explored areas, such as the adoption of UAVs in post-emergency management in China.

Secondly, the case study method enables a comprehensive understanding of the phenomenon by examining the socio-political, environmental, and institutional contexts in which UAVs are incorporated into WEM systems. This is especially significant for a region such as Sichuan, which presents distinct topographical and administrative challenges.

Thirdly, flexibility in research design is evident as case research facilitates the iterative refinement of research questions and concepts throughout the data collection and analysis stages. This adaptability is beneficial in intricate, real-world contexts where new insights can arise dynamically.

Lastly, multi-perspective insights can be employed in case research, for instance, triangulated data sources, including practitioner interviews, document analysis, and policy reviews to offer a comprehensive and nuanced understanding of stakeholder experiences, systemic constraints, and organizational capabilities, thereby enhancing both empirical depth and theoretical contribution.

In conclusion, the strengths identified and the exploratory nature of the research render the case study method both methodologically suitable and practically effective for addressing the research questions. This enables a comprehensive analysis of UAV integration in wildfire emergency management throughout the entire disaster cycle, enhancing both academic knowledge and practical policy discussions. The subsequent sections outline the selection of the case site, the recruitment of participants, and the analytical methods utilized to implement this research design.How to select the case site and respondents, and data analysis methods will be explained next.

4.2.4 Case site selection

Bhattacherjee (2012) suggests that the case site selection should be based on theoretical considerations rather than randomness, for instance, to replicate previous cases, to extend preliminary theories, or to fill theoretical categories or polar types. Based on the research objective, this research is expected to extend the theme of technology adoption to the WEM system, which aligns with the extended preliminary theories on WEM.

Besides, carefully ensure that the selected sites fit the character of research questions, the case site of Sichuan Province encounters the increasing threats of wildfire in recent years although the whole country's wildfire frequency is in a downward trend, while the region still rely on traditional wildfire data collection method rather than adoption with the advanced techniques, which initiated from the ministry of wildfire emergency department. Furthermore, the unique variance in topography in the mountainous and plateau areas can be a good representative as the wildfire study target for future reference for other regions.

In summary, the case selection with Sichuan Province is reasonable not only to align with the extension of the research theme but also to fill the research gap on the lack of qualitative study on WEM.

4.3 Operationalisation

4.3.1 Data collection method

Operationalization is the development of specific research procedures or operations that will result in empirical observations representing the concepts in the real world (Abutabenjeh & Jaradat, 2018). Part of this process is deciding how the desired data will be collected (Abutabenjeh & Jaradat, 2018).

This study employs a qualitative data collection form, aligning with its inductive and exploratory research framework. Qualitative methods are suitable for obtaining rich, context-dependent insights, especially in ares where theoretical development is still emerging (Bhattacherjee, 2012). Compared with quantitative approaches that focus on measurable results and metrics, qualitative inquiry enables a comprehensive understanding of stakeholder perspectives, institutional practices, and specific implementation challenges, which are central to this study's investigation of UAV integration into China's WEM system.

Due to the regulatory, technological, and organisational complexities of UAV adoption in real world, qualitative methods are properly for exploring the meanings and experiences of stakeholders across different WEM phases. The primary method of data collection is interviews, chosen for their flexibility and depth, while supporting documentation and media reports are utilized to triangulate findings.

4.3.2 Interview instrument

This study utilises semi-structured interviews to apply the qualitative approach, ensuring consistency among respondents while allowing for the exploration of emerging themes (Britten, 1995; Jamshed, 2014). This section focuses exclusively on unstructured and semi-structured interviews, as structured interviews typically yield quantitative data (DiCicco-Bloom & Crabtree, 2006). Unstructured interviews resemble conversations, marked by flexibility and the absence of predetermined questions, facilitating spontaneous topic exploration (Jamshed, 2014). Semi-structured interviews utilize a flexible interview guide that includes open-ended questions, allowing for a framework while enabling the exploration of emerging insights in greater detail (Britten, 1995).

Semi-structured interviews provide a balanced methodology, combining the specificity of structured interviews with the flexibility of unstructured formats, which may lack focus (Jamshed, 2014). Semi-structured interviews are effective for theory-informed exploration, particularly when employing analytical frameworks like the TOE framework and the H-EMLC theory. These frameworks facilitate the examination of UAV integration across various emergency management stages while accounting for the institutional, technological, and regulatory factors influencing adoption. Hence, questions are formulated based on the theoretical framework and then refined in Chinese to ensure clarity for case site stakeholders in terms of culture and language.

4.4 Population and sampling

In this stage, the author ought to decide who or what to study, which is the targeted group to draw conclusions (Abutabenjeh & Jaradat, 2018). The decisions about population and sampling are related to decisions about which research method to use (Abutabenjeh & Jaradat, 2018). For population, the interviewee should come from the case site from the city and county level. For the final population of the interviewees, as guide by Cobern & Adams (2020), the size should not be estimated ahead of time but keep interviewing until reach a sanduration point where the author stop getting unique opinions, which is based on the previous literature on the opinion and application of UAVs in WEM.

For sampling, mainly using the expertise sampling (Bhattacherjee, 2012) to the WEM managers who are sufficiently know the policy and organisation structure, UAV operators, who are experts on operational and technical metrics. As well as the snowball sampling (Bhattacherjee, 2012) by identifying a few respondents that match the criteria for inclusion in this study, and then asking them to recommend others they know who also meet this selection criteria, which will introduce in this section.

4.4.1 Interviewee selection

In qualitative research, the identification of the appropriate study population and the selection of suitable sampling strategies are critical for acquiring relevant and contextually rich data. This research employs an exploratory case study design, concentrating on individuals engaged in wildfire emergency management (WEM) activities in Sichuan Province, specifically at the city and county levels, where policy implementation and operational decisions converge.

Population selection criteria is determined by the research design and its methodological orientation, as suggested by Abutabenjeh and Jaradat (2018). Firstly, this study conducts expert sampling (Bhattacherjee, 2012) to obtain key informants with firsthand knowledge and expertise regarding the adoption and use of UAVs in WEM contexts. These individuals comprise emergency management officials, UAV operators, and frontline community patrol personnel. Secondly, snowball sampling is utilized to broaden the respondent pool and improve coverage, wherein initial participants are requested to suggest additional individuals who fulfill the inclusion criteria (Bhattacherjee, 2012).

Three main targeted groups are selected for interviews:

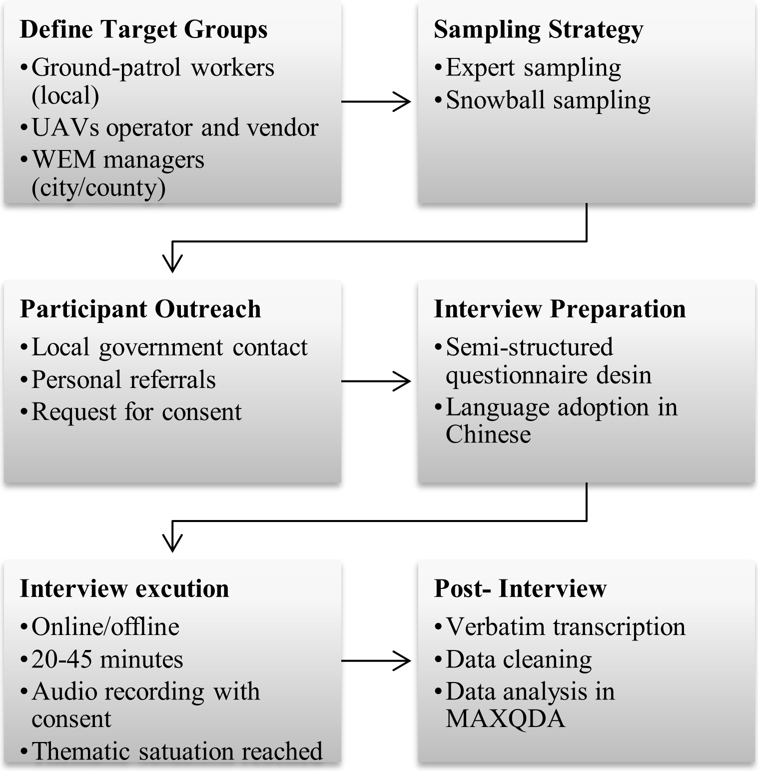
1. Community ground-patrol workers, who engage in practical wildfire prevention and response efforts. Their viewpoints can provide an understanding of the practical aspects of early detection and risk mitigation, as well as their anticipations concerning the future function of UAVs. Ground-patrol workers are from the community level.
2. UAV operators and vendors are familiar with in UAV-based data collection and monitoring function, and provide essential insights regarding the technical

capabilities, deployment practices, and integration challenges of UAVs throughout different phases of the WEM life cycle. UAV operators and vendors may be range from local to provincial entities and they have mature operation experience in mountinous regions.

3. WEM Managers are officials engaged with resource allocation, coordination and execution of WEM plan at city and county levels.They can give strategic information about institution capacibility, what the decision-making process are, and how UAV technology can be used to help national and provincial emergency management goals. WEM managers range from local team leaders to officials at the departmental level within county and city administrative.

Despite selection aimed at promoting diversity within institutional roles and geographic regions, practical feasibility plays a crucial role in determining access. Community patrol workers and UAV operators are typically more reachable through local networks and referrals. Access to senior administrators and high-level policymakers at the provincial or national level is constrained by bureaucratic hierarchies and institutional gatekeeping, which are prevalent challenges in public sector research in China. As a result, the study prioritizes WEM managers at the county and city levels due to their strategic relevance and practical accessibility.

Sampling continues in an iterative manner until thematic saturation is reached, which is characterized by the absence of new relevant themes or insights and further interviews are no longer contributing novel conceptual information (Cobern & Adams, 2020). Saturation was evaluated based on the recurrence and redundancy of codes linked to the TOE framework and the H-EMLC theory. In total, seven participants were interviewed across three stakeholder categories: UAV operators, community ground-patrol workers, and city/county-level WEM managers. (See Appendix 1)Although the initial plan aimed for a minimum of three participants per group; however, access constraints, particularly in engaging high-level administrators, restricted the total number of participants. However, the diversity of roles and perspectives represented ensured a sufficiently rich dataset, particularly given the exploratory nature of this case study. Although complete intra-group saturation may not have been achieved across all categories, cross-group thematic saturation was noted, especially concerning recurring themes associated with institutional barriers, UAV capabilities, and policy restrictions.



Source: the author

Figure 4.3 Interview data collection workflow

Interviews are conducted in Chinese, either online or in person based on participant preference. Each interview session is estimatedly to last between 20 - 45 minutes and adheres to a semi-structured interview guide formulated in alignment with the TOE framework and the H-EMLC theory. Interviews are recorded and transcribed with participants' informed consent to ensure data accuracy, the whole process can see Figure 4.3. In addition, ethical considerations regarding privacy, confidentiality, disclosure, and voluntary participation are rigorously followed.

4.4.2 Documentation selection

The documentation in this research is complementary data that is expected to gather the regulatory data and industry report (Abutabenjeh & Jaradat, 2018). Firstly, the internal government released documents on wildfire distribution regions and frequency yearly, policies and regulations on the WEM; yearly WEM plan in the national level and local provincial level, and UAV operations regulations from the central and provincial levels, as well as the WEM department's resource allocation procedures, procurement information. They can originate from the website of the CPC government, MEM, the

WEM department in Sichuan Province, etc. Secondly, the external document with UAV conference, media coverage to have the data on the application in real WEM practice and its different product types with operational metrics on data collection and communication strengths and weaknesses. Besides, the industry report and recent conference report from China, alongside the UAV vendors' website on the application and practice of UAVs in WEM from Sichuan Province. In the end, all the material will be compiled and categorized before import to MAXQDA for a more effective document labeling in the data analysis stage.

4.5 Observation and data processing

Observation is a way to collect empirical data, and each research method has suitable observation techniques (Abutabenjeh & Jaradat, 2018). In qualitative interview research method, after finishing the recording material collection, which is not immediately interpretable, the author needs to choose data analysis techniques to translate data into qualitative terms (Abutabenjeh & Jaradat, 2018). The original language is Chinese, so first, transcribe the recording with Words, and import all interview materials and documents with group categories into the data analysis platform.

For other qualitative documents, after collecting from the disclosure material from the government website, searching engine platform, and WeChat official account disclosures, clearly segment the unnecessary and irrelevant information, and filter with the most recent and highly related to the theme of UAVs integration in WEM as well as the regulations mentioned by the interviewees. After that, categorize with government documents, UAV industry reports, media coverage, conference academic reports and literature review section of this research into the qualitative analysis platform.

4.6 Analysis and application

This section outlines the analytical process and its methodological foundations for results present. According to Abutabenjeh and Jaradat (2018), the final stage of qualitative research involves interpreting coded data to produce meaning and clarify the application of findings. This study utilised a theory-informed thematic analysis approach, supported by structured content analysis techniques (Bhattacherjee, 2012). The widely used tool

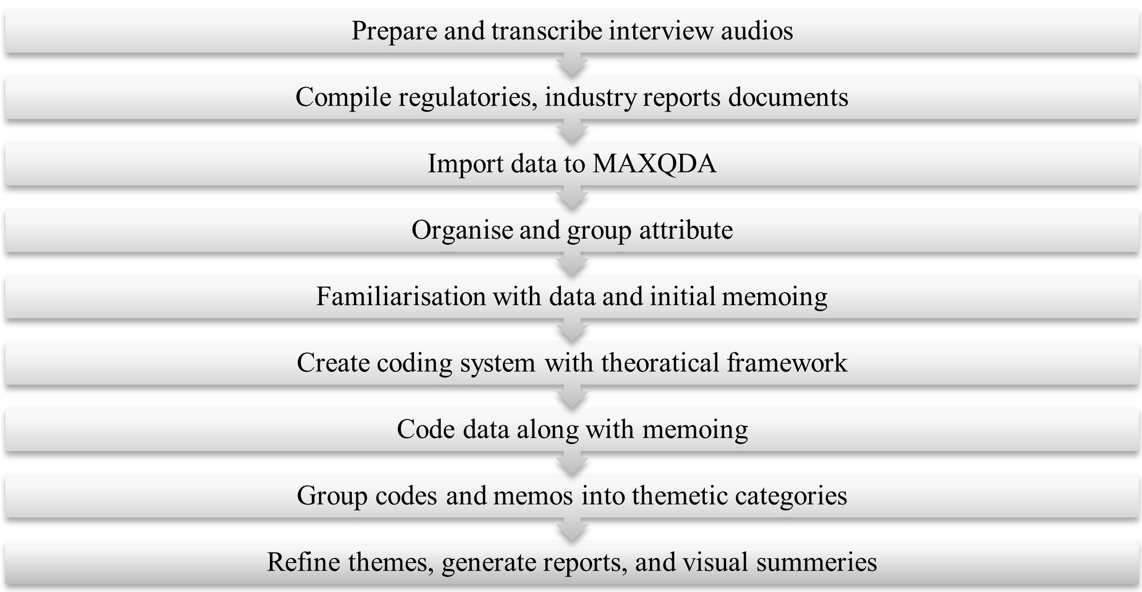
MAXQDA was selected to analyze qualitative semi-structured interviews and regulatory documents.

4.6.1 Data analysis technique

Qualitative data analysis entails interpreting textual material such as interview transcripts and policy documents. According to Bhattacherjee (2012), three common strategies include grounded theory, content analysis, and hermeneutic analysis. Grounded theory abandons pre-established frameworks, while hermeneutics focuses on profound textual interpretation. In contrast, content analysis emphasises systematic categorisation and coding based on structure and meaning. Content analysis is the systematic analysis of the content of a text (e.g., who says what, to whom, why, and to what extent and with what effect) in a quantitative or qualitative manner (Bhattacherjee, 2012).

This study adopts thematic analysis informed by content analysis, guided by the TOE framework and H-EMLC theory because this thematic analysis approach supports both objectives of theory-informed exploration and open discovery of emergent insights.

The analysis followed five broad phases adapted from Bhattacherjee (2012): (1) Transcribing interview data and organising policy documents; (2) Initial data familiarisation and memo writing; (3) Creating a preliminary coding system using the theoretical frameworks in English; (4) Systematic coding using MAXQDA, with emerging sub-themes documented in analytical memos in English; (5) Synthesising coded data into broader themes and interpretations. The full workflow can see Figure 4.4.



Source: the author

Figure 4.4 Data analysis process

4.6.2 Present the results

MAXQDA was employed to support the structured coding and organisation of qualitative data. An initial manual review of the transcripts informed the development of a deductive coding system based on the TOE and H-EMLC frameworks. In the analysis phase, codes and sub-themes were refined to reflect emerging insights with an inductive coding system. The resulting themes are presented in the next chapter and structured around the study's theoretical lenses, while also highlighting unexpected findings, inter-theme insights, and contradictions compared to the existing literature.

Given that the interviews were conducted in Mandarin Chinese, the transcription and interpretation were performed in the original language within MAXQDA to maintain conceptual nuance and context. While the coding system and analytical memos were developed in English to align with the thesis's theoretical frameworks and reporting language, the data interpretation process was conducted in Chinese. This process (see Figure 4.5) ensured the accurate representation of participant intent before assigning English-language codes.

Source: the author

Figure 4.5 Translation and coding workflow from Chinese source transcripts to English-language presentation

To ensure accessibility for an English-language academic audience, selected interview quotes and policy documents were translated into English through a combination of Google Translate, DeepL, and manual review by the author due to preserve semantic accuracy, cultural nuance, and contextual clarity. The English translations of transcripts are included in Appendix 4, and the original Chinese-language quotations are available upon request to ensure transparency. Therefore, this approach allows readers to follow the complete analytical process from raw data to final interpretation, preserving both linguistic integrity and academic rigor across languages.

4.7 Ethical considerations and limitations

The ethical principles in this research for data collection and analysis are followed with Bhattacherjee (2012).

1. Voluntary participation and harmlessness

Since the interview target group is a relatively sensitive profession in China, the subjects must be aware of the voluntary participation and have the freedom to withdraw from the study at any time without any unfavourable consequences, and they are not harmed as a result of their participation or non-participation in the project. Verbal and written consent were obtained before each interview.

2. Anonymity and confidentiality

To protect the interests and future well-being of the participants, their identities must be protected in scientific research. Anonymity means that the researcher or the reader of the final research report cannot identify the responses of specific respondents. This principle will be strictly applied to the data analysis and final report of this study. When collecting and storing data, all audio recordings and original transcripts will be securely stored in encrypted folders, which only the author can access. The names, exact addresses, company names, and any directly identifiable references during the interviews will be hidden in the final report, and only city-level information will be provided. All citations and references have been anonymised, such as Interviewee A. Identifying information such as names, specific organisational roles and town identifiers has been removed or simplified. Only city-level identifiers (e.g., A City, B County) are used to indicate context..

3. Disclosure

The author should provide basic information about this study to potential participants before data collection to help decide whether or not they wish to participate in the study. Before the conversation, the research motivation, research objective, methods, and expected duration will be introduced briefly to the interviewees. After the interview, a briefly condensed report about the research results will be sent back to the participants.

4. Analysis and reporting

The author has the obligation to disclose the research progress on how data is analysed and reported in this study to the interview participants and future audiences. Unexpected or negative findings should be fully disclosed, even if they cast some doubts on the research design or the findings, and be honest with the complete and proper data analysis.

Limitations

Despite efforts to diversify the sample and integrate multidimensional perspectives, the findings may be limited by the exclusion of high-level provincial and national policy makers whose perspectives on strategic policy integration of drones may provide more insights. In addition, due to access and time constraints, this study only selectively covers some municipal data rather than being exhaustive. Moreover, a methodological limitation is that the ability to capture non-verbal and para-linguistic cues (e.g., intonation, pauses, and emotional expressions) is weaker during interviews, especially online interviews. This limits the depth of nuanced interpretation during transcription and thematic coding, especially in terms of understanding implicit meanings or emotional responses.

The author must acknowledge these limitations and help relate the findings to the operational and mid-level administrative realities of the WEM in Sichuan Province. Moreover, the author try to mitigate the bias by including participants from various municipalities to capture variation across different implementation contexts. To address potential sampling bias, respondents from both technologically advanced and less-developed regions are included, and interview findings are complemented with documentary data from the official disclosure websites for holistic analysis.

5 Results

5.1 Overview of the data sources

In this qualitative research, the goal is to assess the opportunities and challenges of the integration of UAVs in China's wildfire emergency management system, with the case study of Sichuan Province. After the interview with the 7 stakeholders from this case site with ground patrol workers, local wildfire managers and UAV operators/vendors, the list of interviewees (see Appendix 1) and the interview questionnaires (see Appendix 2) can be found in the Appendix section. The analysis material collection and conduction range from 1 February, 2025, to 12 May, 2025, including the 7 interview transcripts, 8 regulation and legal documents from the CPC central government website, the Sichuan Province Government website, the MEM, the Department of Wildfire Management in Sichuan Province, 11 UAV application media reports in Sichuan Province, 3 academic UAV usage in WEM conference reports, and 1 literature review. In this research, these qualitative data were analysed with the MAXQDA software with theme coding and memoing; the themes and emerging thoughts are categorised with the TOE framework and divided into the usage of UAVs with H-EMLC theory. Noted that the selected quotations are originally in Chinese; in the findings chapter are translated into English for consistency and communication with Google Translate and DeepL Translate, alongside the author's manual review to minimise the meaning bias and variation in different language contexts while keeping the original statements in footnotes. The total code system (see Appendix 3) has 6 categories with a total of 439 coding segments.

Therefore, this chapter mainly focuses on presenting the key findings to answer the research question around the key theme structures under the guidance of the conceptual framework of TOE and wildfire management life cycle theory to demonstrate the UAVs' integration in China's WEM system in different phases through pre, during, and post-wildfire with the technological, organisational and environmental opportunities and challenges. And follows with the cross-cutting themes and summary of the findings.

5.2 Technological strengths and limitations

In Sichuan Province, which is characterised by mountainous terrain and frequent wildfires, UAV technology has specific operational advantages and challenges due to unique local conditions. UAVs have demonstrated their significant capability in WEM by enhancing real-time detection, monitoring functions, material transportation, and operational efficiency, though they coexist with technical constraints like battery life limitation, signal reliability, and payload restrictions. The insights under this theme mainly come from media coverage of UAV applications in WEM and interview participants: UAV operators and vendors and the UAV application conference reports.

This section mainly addresses the integration of UAVs into the WEM system with technical capabilities and operational limitations under the " Technological" dimension of the TOE framework. The sub-theme of capability encompasses function, battery life, payload, and flight endurance.

5.2.1 Real-time monitoring and detection

The UAVs' capability strengths for WEM can be seen in data and sensor facets. UAVs deployed in WEM operations in Sichuan demonstrate strong capabilities for rapid, real-time monitoring and detection, significantly enhancing early response effectiveness, especially in mountainous and hilly areas. According to a news report, UAVs equipped with thermal imaging cameras, LiDAR, meteorological sensors, and real-time data transmission systems enable "all-weather monitoring of fire conditions", including "accurate location of fire points with a sensitivity up to 0.1 degrees Celsius" (Wang et al., 2025). These features allow for three-dimensional fire spread modelling using temperature, wind speed, and vegetation density data, facilitating timely and informed emergency response.

These strengths were consistently noted by interviewees. Interviewee E remarked that UAVs can *"collect wildfire data in a short time; response speed reaches minutes."* Interviewees A and B stated that UAVs are *"more efficient than manual and traditional methods of extinction prevention"*, while Interviewee F estimated that UAVs *help "save at least 10–20%* on labour and financial resources".

However, the interview data also revealed operational limitations, especially in terms of flight time and scheduling. Six out of seven respondents identified battery limitations as a key issue. Interviewee F described this as the *"most fatal flaw"* and emphasised that even with high-capacity sensors, insufficient flight time would limit continued operations. In addition, challenges in prioritising flight routes and allocating operational teams were both a test and an opportunity for emergency management departments to strengthen coordination.

Accordingly, one successful practice from Liangshan Autonomous Prefecture, one of the sub-administrations of Sichuan Province in 2023, proved that combining eight autonomous drone routes and three all-weather patrol routes enabled continuous monitoring with real-time image transmission to the command centre for data-supported decision-making (DJI, 2024). This UAV-employing case showed the application extends to the preparedness phase in prescribed burning support, rather than focusing on early detection and during-wildfire monitoring.

To address existing limitations, interviewees proposed several technical improvement suggestions. These included enhanced battery life, improved charging systems, and alternative fuel strategies. Interviewee F suggested that *"hydrogen energy should be developed as the mainstream, and maintenance costs can be reduced*", aligning with global sustainability trends and cost-saving goals.

5.2.2 Mobility in remote and hazardous terrain

UAVs can effectively reach difficult and dangerous areas that are inaccessible or risky for human patrols and vehicles, as they dramatically improve detection and response speeds in mountainous regions. As Interviewee F noted, *"[UAVs are] able to reach fire points that vehicles cannot reach."* The capacity of high mobility provides the WEM response team with faster detection and response action towards the wildfire accidents in steep terrain or dense vegetation of western Sichuan, improving both efficiency and personnel safety. Especially*, " to follow the principle of human life first in organisational decision-making."* (Wang & Zhang, 2023, p. 3)

However, the actual effectiveness of UAV mobility is highly dependent on operational conditions in the operational environments and digital infrastructure. As Interviewee G stated, *"Signal is a big problem in mountainous areas. Once the signal is lost, the drone cannot be controlled and will fall."* In addition, communication challenges and limited battery capacity were identified as core barriers to sustained UAV usage in extended operations. Interviewee F further explained that *"In hilly areas, the battery runs out after about 1 km of flight."*

To address these challenges, several interviewees suggested operational strategies such as pre-scheduling flight routes and using drone clusters to ensure coverage and continuity, even when individual drones face power or signal limitations. Moreover, improvements in battery endurance and fuel efficiency were cited as essential for expanding UAV utility during wildfire response.

In summary, while UAVs offer valuable mobility benefits during the early and active phases of wildfire management, their effectiveness depends on not only environmental infrastructure but also strategic planning and technical enhancements, particularly in battery performance and flight communication reliability.

5.2.3 Payload capacity and multi-function integration

Interviewees emphasised the growing payload capacity of UAVs as a critical factor in expanding their functionality in WEM. According to Interviewee G, "*I don't think the load capacity is a problem since it keeps improving.*" This capability enables UAVs to carry advanced technologies, such as high-resolution cameras and infrared imaging systems, thereby improving surveillance under challenging weather or visibility conditions. As noted, UAVs can also be prescheduled to operate during both day and night conditions, including *"flying over obstacles during the day and autonomously* navigating at night."

Beyond surveillance, increased payload capacity supports material transport during various wildfire phases. Interviewee G noted that UAVs *"conventional load capacity of T60 is 50 kg, and that of T100 is 75 kg… the load capacity of 50 kg is appropriate." Besides, UAVs can spray "50 kg of water in two minutes"* to control small fires during wildfire events. In the recovery phase, UAVs have been used to transport saplings and soil to inaccessible areas. *"As one example from Tibet illustrates, UAVs played a key role in post-disaster ecological restoration by delivering saplings and water to rocky mountain areas,"* stated Interviewee G. However, it is also noted from the interviewee G that the large load capacity for the drones is also associated with huge *"downward pressure for takeoff and landing, and it is easy to damage vegetation."*

Thus, the increasing payload ability of UAVs plays a crucial role in integration with multiple advanced technologies for wildfire detection and monitoring while assisting in suppressing wildfires and recovery material transportation. Such technological enhancements have been consistently underscored in previous research as transformative for proactive WM in pre-, during, and post-wildfire applications, with the integration of another external technology system to maximise the effectiveness of UAVs.

Table 5.1 Main results from technical aspects

Factors	Advantages	Disadvantages	Suggestions
Real-time monitoring and detection	▪ Early response ▪ Time and labour saving	▪ High operation skills ▪ Schedule route	▪ Enhanced battery life and develop alternative fuel: hydrogen energy
High mobility and access to hazardous areas	▪ Personnel safety ▪ Effectiveness in ignition point approach	▪ Signal unstable ▪ Battery life	▪ Pre-scheduling flight routes and drone clusters
Payload capacity and multi-function integration	▪ Equipped with advanced technology ▪ Conduct extinction tasks ▪ Transport material	▪ Huge drones with high landing pressure, damage to vegetation	▪ Coordination of different types of drones in multiple phases ▪ Operation skills upgrade

In summary, this section highlights noteworthy strengths of UAV technology in real-time monitoring and detection, remote area accessibility, and payload capability are widely recognised. Key takeaways can see Table 5.1. Drones in Sichuan's operational challenges related to battery life, endurance and signal reliability appear intensified due to its complex terrain. These findings underscore the necessity of comprehensive technical improvement, organisational training, and regulatory flexibility, aligning with insights from existing literature and enhancing the understanding of the conditions necessary for the successful integration of UAV technology into WM operations.

5.3 Organisational capabilities and constraints

In addition to technical aspects, the successful integration of UAV technology into Sichuan's WEM system relies heavily on internal organisational capabilities and preparedness because a clear and structured organisational framework is crucial for fostering UAV adoption in the WEM system. Based on interviews with patrol workers, wildfire managers, and UAV vendors, this section identifies four key organisational themes: (1) decision-making and command structure, (2) financial management, (3) human resource training, and (4) interagency coordination. These themes correspond to the "Organisational" dimens.

5.3.1 Decision-making and command structure

Organisational decision-making capacity plays a critical role in every phase of WEM, directly affecting UAV adoption, operational strategies, and procurement investment. Respondents highlighted gaps in staff capabilities, interagency coordination, and internal culture, particularly in under-resourced sub-administrative areas.

On the one hand, Sichuan Province has established a relatively mature hierarchical command system for WEM. Interviewee G noted that *"The government attaches great importance to the formulation and implementation of emergency plans."* For instance, the provincial government issues annual mandates such as the 2025 Forest Fire Prevention Order and the 2025 Grassland Fire Prevention Order, while agencies like the Sichuan Forestry and Grassland Bureau and the Emergency Management Department publish guidelines and daily fire risk assessments to support city-level planning.

Despite this structured system, interviewees expressed concerns about the adaptive capacity of organisations to incorporate UAVs. Interviewee E emphasised that *"how to collaborate and make decisions is a reflection of organisational capabilities."* They raised strategic questions about internal skills training, the introduction of external experts, and adjustments to command protocols. Interviewee B also referenced resistance to reform in areas where traditional patrol models persist: *"Our community still uses the old way—residents and militia patrols."*

These perspectives underscore that UAV adoption is not merely a technical decision but a test of organisational resilience and willingness to adapt. Strategic leadership and interdepartmental coordination are key to realising the full potential of UAVs in emergency contexts.

5.3.2 Financial management and investment strategy

Interviewees frequently identified financial considerations as either facilitating or hindering UAV deployment. Interviewees A, B, E, and G recognised the role of state funding in fire prevention efforts within high-risk urban areas. Interviewee A indicated that *"we were allocated funds to purchase, use, and maintain drones,"* while Interviewee E highlighted that *"every year, the state provides strong support for Sichuan's forest fire funding."* The finance allocation from the state illustrates the importance of external policies prioritising wildfire management, which enables the procurement of drone devices with specialised data analysis platforms and other WEM techniques for supporting command operations for wildfires.

In contrast, certain cities had not yet implemented UAVs owing to a limited perceived return on investment. Interviewee B indicated that there is a standard fire prevention period of six months annually. Purchasing and maintaining drones requires long-term investment. They acknowledged the potential for drones to serve broader disaster management functions, stating, *"It is not only useful for wildfire prevention but also for other disasters."* The idea of extending the usage of UAVs not solely for one disaster can mitigate the concerns about the limited usage period at a relatively high cost. In addition, charging for battery and maintenance costs was also an additional concern. Interviewee F noted that the cost of charging is 6-8 Yuan per battery per session and that repairing electric drones at low altitudes is a viable option. If they rely solely on patrol power, repair is not feasible as the battery will immediately fail. Additionally, Interviewee B noted that organisational conservatism presents a barrier: *"The organisation is conservative and afraid of risks."*

In summary, while funding is available, the financial strategy for procurement and training programmes depends heavily on local priorities, risk perceptions, and cost-benefit analyses. The future investment rationale may evolve if the benefits of multi-disaster use cases and long-term returns are more effectively demonstrated.

5.3.3 Training and role transformation

Staff training is key to organisational readiness regarding UAV integration in Sichuan's context. The interviewees emphasised the necessity for WEM human resources skill training and development, interagency drills, and simulation exercises.

In December 2024, the Sichuan Provincial Forest Fire Prevention Office issued a province-wide training mandate covering hundreds of counties and villages. For example, Chengdu's WEM department executed full-scale drone-assisted drills that simulated actual wildfire scenarios and educated teams on UAV history, system metrics, and operational coordination (Sichuan Provincial Emergency Management Department, 2025). Consequently, the personnel and interagency team training, as well as the WEM response team drills for the application of UAVs before the wildfire, enhance the capability of the WEM response team. Moreover, interviewees highlighted that training encompassed not only simulation but also practical on-site capability development. We also invited private sector UAV vendors as trainers. Interviewee F stated, *"The government invited us to conduct UAV operation training."*

However, deficiencies in skills and issues related to safety persist. Inadequate operation of UAVs may result in significant repercussions. Interviewee F cautioned about the potential for *"drone explosions causing secondary fires",* whereas Interviewee A noted that *"unexpected landings necessitate additional personnel for retrieval."* Furthermore, Interviewee F noted *that "if frequent erroneous operations occur, the public will also lose trust in the integration of UAVs for WEM."* These examples illustrate the necessity for operational competency for WEM single crews and whole teams, especially in remote areas.

Importantly, UAVs were not regarded as threats to employment. Interviewee A expressed the belief that the job will persist because "you need people to operate drones, and firefighting still needs teams. Roles will change, not disappear." Interviewee C stated, *"I am well-acquainted with my forest area. That experience is valuable for planning and recovery."* These responses indicate that patrol workers view the use of UAVs as a chance to change their roles rather than take them away; besides, they emphasise the importance of local knowledge from community members in planning flight paths and for identification and controlling wildfires. Particularly, interviewee A mentioned the patrol job transfer to local volunteers: *"The role of protecting the safety of residents around the* *forest when having the training on response."* As a result, the positive attitude for reframing would also be beneficial for the human resources improvement in the internal WEM response team.

Nonetheless, challenges remain in aligning training content with wildfire realities. Interviewee G criticised the existing training programmes: *"Now, platforms only teach operation. For wildfires, you need to understand basic taboos and laws."* They suggested nation-level standardisation and accountability for pilot licences to address these gaps. However, this statement also highlights the dilemma of needing to broaden the training content while simultaneously increasing costs for UAV training entities.

In short, the UAVs' training in operation and basic common sense in this industry and WEM is crucial for the organisation when adopting the UAVs for different phases of wildfire. Although the staff within the WEM team are positive about the job reframing, the training standards and the training gap between the simulation and reality should be considered in the effective integration of UAVs into the existing WEM system.

5.3.4 Interagency and platform coordination

Effective UAV integration not only relies on coordination between various WM agencies and departments but also between patrol teams, emergency commanders and drone operators. Interviewees highlighted both successful collaborative practices and substantial challenges in inter-agency communication and cooperation. As mentioned by interviewee C perceived the importance of the coordination between the ground patrol work and the emergency response team once they detected the wildfire in their communities: "We ground workers need to report to the EM department at once about the basic information on the wildfire, and the firefighting team will support the suppression." Interviewee E elaborated*: "Drone operators collect terrain, vegetation, roads, and water source information to assist emergency decision-making."* However, coordination and allocation challenges persist, particularly between detection UAVs, transport UAVs, and traditional resources like helicopters. Besides, as one interviewee added, "Data synchronisation between different models and brands needs improvement."

Additionally, interviewee A pointed out difficulties in seamlessly connecting across agencies in different phases of WEM; in other words, it is about the post-processing issues of drones obtaining fire scene information and emergency rescue arriving at the scene.

Interviewee A remarked, *"Patrol is preventive, firefighting is reactive, and the two are not aligned."* Interviewee F suggested better coordination across detection and suppression systems and called for cross-agency data sharing and regional collaboration mechanisms.

These insights indicate that organisational silos, technical fragmentation, and procedural gaps must be addressed to optimise UAV contributions to wildfire response. Realising the seamless connection between drone wildfire detection and human response is difficult in real-world practice. Therefore, the combination of detection, extinction and transportation drones' cooperation effectively realises early proactive responses for wildfires while promoting cross-regional and cross-agency wildfire data sharing and action collaboration when encountering large-scale incidents. This recommendation outlines specific steps to enhance organisational readiness and effectiveness in the integration of UAVs for wildfire management. Key findings can see Table 5.2.

Table 5.2 Main findings from organisational context

Sub-themes	Enblers	Barriers
Decision-making and command structure	▪ Clear guidance on WEM ▪ State and local WEM plan	▪ Conservative culture ▪ Organisational capability
Financial management	▪ State finance allocation	▪ Cost of procurement ▪ Limited hazard application period ▪ High cost for charge and maintenance
Human resources training	▪ Positive attitude on reframing ▪ Training platform accessible ▪ Personnel and team drills	▪ Training gap ▪ Training plan and reality disparity ▪ The training standard is limited
Interagency coordination	▪ Local knowledge in UAV route design	▪ Disconnected from the detection and response ▪ Procedural gaps

5.4 Environmental enablers and barriers

In this theme, it mainly analyses the external environmental factors determining the integration of UAVs in WEM systems within Sichuan Province. The factors categorised under the "Environmental" dimension of the TOE framework include regulatory policies, operational permissions, privacy and ethical considerations, digital infrastructure, and market accessibility. They can be seen either as an enabler or a barrier for the UAVs' adoption. In short, this section explores these contextual influences, integrating insights from both interviews and policy documents.

5.4.1 Airspace control and regulatory constraints

The regulatory frameworks governing UAV use were recognised as having both supportive and restrictive elements. On one hand, national and provincial policies encourage UAV innovation in WEM practices. Initiatives facilitate the growth of aviation monitoring teams, provide training for drone operators, and enhance the utilisation of domestic UAV technologies for data collection and wildfire surveillance.

Nonetheless, limitations on airspace access, flight altitudes, and operational zones continue to pose a substantial obstacle, as the interviewees G and F both stated that the issue was the *"airspace limit and speed limit"*. Four of the seven interviewees expressed concerns regarding the navigation of no-fly zones, particularly in mountainous areas and regions at high risk for wildfires. Interviewee A stated, *"It is essential to verify the no-fly zone prior to operation to prevent violations."* Interviewee G highlighted the importance of caution regarding temporary airspace controls, noting that they may change unexpectedly. Particularly in the mountainous areas of Sichuan Province, the restriction on the flight area can hinder the whole region's wildfire situation monitoring and detection during the high wildfire frequency periods. Besides, different UAV types are also subject to varying speed and height restrictions mentioned by interviewee G, making coordination within the drone teams more complex for executing detection and suppression tasks with UAVs.

Additionally, certain regions have already privatised low-altitude airspace. Interviewee F stated that *"The under 5km flight zone here has already been acquired by private companies, and future drone flights may necessitate payment."* While regulatory backing exists at the national level, practical restrictions on flight permissions and area access considerably restrict UAV functionality during essential fire periods.

Therefore, the application of UAVs in WEM, although it is supported by the national initiative on WEM innovation and aerial monitoring capability upgrades with more investment in domestic drones, also faces constraints on the airspace and flight speed regulations.

5.4.2 Registration and operational approval

Despite the diversity and widespread availability of UAV products, operational procedures are subject to strict rules and regulations. Interviewee F stated that *"all drones are required to be registered with the public security bureau and must be purchased with liability insurance. Noncompliance may lead to immediate confiscation, regardless of insurance status."*

Formal permission is also required for flight operations. in order to legally operate the UAVs, the permission for the flight needs to be approved by the air traffic management agency 30 minutes before the planned take-off. *"When performing particularly urgent tasks, the unit can submit a flight activity application at any time, it will be approved 10 minutes before the planned take-off."* Anyway, the UAVs' operation in WEM at any circumstances still follows the flight permission beforehand. This requirement can delay emergency responses and restrict real-time operational flexibility during wildfire incidents.

Although these procedures aim to enhance safety, they impose administrative burdens on WEM organisations and restrict responsiveness in rapidly changing fire situations.

5.4.3 Privacy, ethics, and public perception

While not the primary focus, several interviewees mentioned privacy issues and ethical considerations associated with drone operations and public perception. On the one hand, UAVs collect sensitive information, including geographic coordinates, thermal imagery, and real-time video transfer, provoking governmental apprehensions regarding potential data misuse or leakage. According to a national policy paper, risks include both *"data interception during transmission"* and *"unauthorised access to national security zones may expose national security secrets and cause irreparable losses".* (Wang et al, 2025, p. 5). Interviewee B further underlined proximity concerns: *"Near military areas or government buildings, this becomes a privacy issue."* Operators are responsible for following both legal restrictions and ethical guidelines in data handling.

On the other hand, public perception of UAVs is predominantly positive, though it varies across different demographics. While some residents appreciate UAV-assisted patrols and suppression and trust domestic brands, others express concerns in terms of frequent operation errors and disruptions to bees. Interviewee E noted that *"traditional patrols and prescribed burns received more complaints",* suggesting drones are often considered an advancement. However, Interviewee F acknowledged that *"if there are too many errors in operation, the public's perception of drones is also sceptical."*

Besides, some residents also raised ecological concerns about potential disturbances to livestock, water tanks, or even pollinators like bees, revealing the nuanced nature of social acceptance. For instance, Interviewee G shared, *"Bees in the flight area, which may be wild or captive. When operating, residents reminded us to stay away."* Despite this dilemma, there have been no reports of public resistance strong enough to prevent drone operations. Therefore, the aforementioned concerns illustrate the importance of operational sensitivity and environmental awareness.

In short, the concerns regarding privacy and ethics are not spontaneous; they illustrate the dual nature of drone development and application.

5.4.4 External digital infrastructure and technology ecosystem

UAV integration in Sichuan's WEM system also depends on external digital infrastructure, particularly in mountainous and remote wildfire-prone regions. Technologies such as RS, 5G, AI, and cloud computing are not merely enhancements, but they are foundational to real-time monitoring, data transfer and analysis for effective response.

The interviewees emphasised this interconnectedness. Interviewee D suggested, *"Drones, AI, 5G, and cloud computing should be combined."* Interviewee E highlighted the need for *"cross-provincial coordination between satellites, RS, drones, and ground teams."* These perspectives demonstrate conformity with China's national initiative to establish integrated wildfire data platforms encompassing space, aerial, and ground components for an enhanced digital emergency response framework.

However, effective use of these external tools also depends on internal organisational capacity. As part of the 2024 Emergency Management Integrated Platform Upgrade, the Sichuan Provincial Government invested in improving data transmission and WEM system infrastructure, showing how environmental and organisational factors are tightly linked to maximise effectiveness and overcome the technical limitation of drones.

5.4.5 Accessibility and market conditions

China holds a globally leading position in drone research, equipment manufacturing, and communication technology nowadays. As of 2023, the number of registered civilian drones in China reached 1.267 million, with over 19,000 drone-related companies nationwide (National Development and Reform Commission, 2024). According to Interviewee F, *"DJI, Xiaopeng, EAVsion, XAG, and TopxGun are well-known brands in the market."* Therefore, this dynamic market environment provides wildfire management agencies in Sichuan with diverse UAV product options tailored to different wildfire phases with multiple functions, ranging from early detection to recovery logistics.

The growing demand for drone operators has also led to an increase in UAV training institutions in Sichuan Province. Interviewee F observed, *"The market competition is fierce, and a large number of training companies have increased in my city within a year."* This expansion includes collaboration between public WEM organisations and private UAV vendors for staff training, contributing to the rise of professional UAV operators both within and outside of government institutions.

However, accessibility challenges remain, particularly in remote county-level cities. Interviewee E, a city-level wildfire manager, noted that *"there are very few local training institutions in my city, and you can only obtain a license in a provincial city."* Limited access to certified training creates a geographical barrier, especially in remote areas where wildfire risks are high. Furthermore, operations for training are required to obtain certification from the Civil Aviation Administration, adding an organisational burden to access.

To address these challenges, Interviewee E suggested facilitating UAV operational training for the local level of WEM response agencies' crews so that frontline workers can quickly realise basic operation in practice. This recommendation points to a need for manufacturers to design more user-friendly systems and data analysis interfaces, while institutions organise license and certification training for broader participation in UAV-based wildfire response.

Table 5.3 Key environmental elements for UAVs adoption in WEM system

Sub-themes	Main takeaways
Airspace control	▪ Speed and altitude regulation ▪ Airspace under 5km privatisation ▪ Restriction on non-fly area ▪ Temporarily added airspace control
Registration and operation approval	▪ Purchase registration ▪ Liability insurance purchase ▪ Permission for operation approval ▪ Pilots license
Privacy and ethical considerations	▪ Government privacy in unauthorized areas ▪ Data governance need ▪ Skeptical attitude from the public ▪ Disturbance to flying insects
External digital infrastructure	▪ RS, satellite, 5G, cloud computing, AI, etc. as support ▪ Integration of a wildfire data transmission platform
Accessibility and Market	▪ Strong market ▪ Need for localised certification

In summary, the contextual factors surrounding the deployment of drones in WEM are not binary, but conditional and complex. National policies and technical infrastructure can support the integration of UAVs, but actual implementation depends on clear airspace regulation, accessible certification, public perception, and organisational readiness. They can be enablers or inhibitors, depending on how and where drones are effectively deployed in wildfire environments. Key findings in this context can see Table 5.3.

5.5 Integration across wildfire emergency phases

This section focuses on the present UAV application in different WM stages, mainly under the guidance of H-EMLC theory, to locate the role of UAVs in pre-wildfire for prevention and preparedness, during-wildfire for response, and post-wildfire for recovery in Sichuan Province. Drawing on interviews with key stakeholders, government documentation, and related reports, this analysis highlights strengths, limitations, and areas for improvement within each stage in the real complex world, using H-EMLC theory as an analytical lens.

5.5.1 Pre-wildfire phase

UAVs have shown usability in the prevention and preparedness phase of WEM. Their functions include early risk identification, fire monitoring, and terrain mapping. Interviewees described UAV deployment for aerial patrol, vegetation analysis, and assisting with prescribed burns. For example, Interviewee E noted that *"drones are capable of facilitating high-altitude patrols and early fire detection, especially in steep terrain."*

Additionally, documents from the MEM disclosure also point out the role of UAVs in proactive wildfire prevention. The national report, Wang et al., (2025, p. 2), emphasises UAV use in real-time imaging and early warning systems. These strategic objectives correspond with H-EMLC theory's emphasis on anticipatory risk mitigation.

In spite of policy initiatives, the implementation of UAVs at the local level administrative regions continues to exhibit inconsistency. Interviewee E highlighted that *"UAV use in the prevention stage depends heavily on annual WEM planning and organisational resource allocation, which are often insufficient or uneven considering the half year for prevention."* Conventional prevention methods, lack of organisational capacity, and uneven adoption across sub-regional agencies create a gap between policy intentions and operational execution.

This discrepancy highlights the urgent need for clearer internal WEM organisational reform and constant support for under-resourced regions to strengthen UAV adoption in early-phase prevention-based management.

5.5.2 During-wildfire phase

The integration of UAVs is most advanced during active wildfire events. UAVs have been consistently recognised by stakeholders for enhancing situational awareness, facilitating safer operations, and promoting timely decision-making. UAVs, equipped with thermal sensors and real-time video transmission capabilities, improve visibility and fire tracking in low-visibility and nighttime conditions. For instance, Interviewee G explained that *"thermal imaging allows immediate identification of hotspots, even at night,"* while an emergency manager (Interviewee E) reported that UAVs *"transmit critical data like fire lines, water sources, distance, and vulnerable structures to the command centre in real time."*

Beyond surveillance, UAVs were also reported to aid in extinguishing fires in hard-to-access areas. Interviewees described applying UAVs to transport suppression materials and conduct extinction tasks, especially when terrain limited vehicle or human access. For instance, Interviewee F mentioned that UAVs can spray *"50 kg of water in two minutes"* to control small fires during wildfire events. In such cases, UAV deployment also serves to mitigate human exposure to high-risk environments and keep the personnel safe first as the priority.

However, operational limitations continue to exist during the wildfire events. Participants identified issues with limited battery life and unstable signal transmission in mountainous areas, which often impede drone performance during critical instances. Therefore, these technical challenges underscore the requirement for improved energy systems, extended-range UAVs, and reliable communication infrastructure to ensure UAV reliability in demanding conditions.

5.5.3 Post-wildfire phase

Among the three wildfire phases, post-fire recovery displays the least structured integration of UAVs. While certain applications are present, including damage assessment, re-ignition hotpot monitoring, and the transportation of restoration materials, they lack systematic implementation and widespread adoption.

Interviewee G stated that UAVs are used to *"assist in transporting saplings, water, and materials*", while interviewee D highlighted UAV support in identifying *"re-ignition risks and secondary disaster"*, *"Rapid assessment of damaged areas and loss"* and *"monitoring changes in soil quality"* were also reported. These practices highlight the UAV capacity in transportation and assessment of land situations as well as potential usage in ecological restoration and secondary disaster mitigation. Conversely, interview data indicate that UAV participation in recovery remains ad hoc. One contributing factor is the blurred boundary between post-wildfire recovery and pre-wildfire prevention for the next event. Interviewee D also observed a lack of explicit organisational protocols and disclosure mechanisms dedicated to post-fire recovery.

This underutilisation reflects a broader challenge of UAV applications noted in H-EMLC theory, which is the tendency to prioritise response over recovery. While theoretical models emphasise equal importance across phases, the findings from Sichuan indicate an operational imbalance, with UAVs primarily concentrated on the emergency response phase. Therefore, these challenges suggest a preparedness and recovery area for future policy attention and resource allocation for WEM organisations.

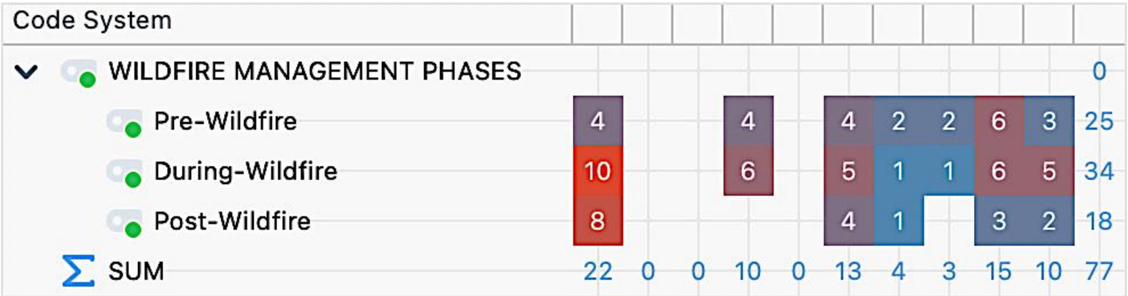
While qualitative insights reveal notable differences in UAV deployment across wildfire phases, particularly underuse during recovery, the coded data analysis from MAXQDA provides a broader visual perspective on these disparities. The following section outlines the phase-wise distribution of UAV usage in the interviews and examines its alignment or divergence from previous findings.

5.5.4 Cross-phase UAV usage visualisation

The following visualisations are based on the systematic coding process conducted using MAXQDA. Data were derived from interviews and media reports and analysed thematically using a hybrid deductive-inductive approach. The predefined themes were informed by the H-EMLC theory, and the codes were iteratively refined based on emerging data.

As illustrated in Figure 5.1, UAV integration is most frequently coded in the "During-Wildfire" phase (34 times), followed by "Pre-Wildfire" (25) and then "Post-Wildfire" (18). Each number represents a specific sub-code (e.g., damage assessment, sapling transport, re-ignition monitoring, secondary disaster detection.) This figure further underscores the disparate adoption of UAVs across phases, indicating a predominance of applications centred on emergency response while exposing areas where restorative uses remain relatively underdeveloped within the context of Sichuan Province.

This imbalance contrasts with the holistic approach recommended by the H-EMLC theory, which emphasises equal attention to preparedness, response, and recovery. Visual coding analysis further confirms these patterns, illustrating a concentration of stakeholder input and thematic content during the wildfire phase. This insight advocates for increased attention and resources for expanding UAV integration in both preventive and recovery phases to improve overall wildfire management resilience.



Source: MAXQDA

Figure 5.1 Visual co-occurrence map with the wildfire management phases

In conclusion, to fully harness UAV technology in wildfire emergency management, it is essential for policy, resource allocation, and organisational practices to adapt to facilitate a more balanced and sustained integration of UAVs throughout all stages of wildfire management.

5.6 Key findings summary

This chapter investigated the integration of UAVs into Sichuan Province's WEM system, organised in accordance with the TOE framework and H-EMLC theory. In the technological domain, UAVs were recognised for real-time data acquisition, high mobility in hazardous terrains for detection and suppression tasks, and payload versatility. However, core limitations were identified, including short battery life and unstable signals in mountainous terrain. Stakeholders suggested solutions such as improved battery technology and a drone clustering strategy.

In terms of organisational capabilities, decision-making structures, financial allocation, human resource training, and interagency coordination significantly shaped UAV adoption. While clear guidelines and state funding facilitated UAV deployment, conservative organisational culture, limited training standards, and fragmented interagency coordination posed substantial barriers.

From an environmental perspective, supportive national policies, complementary digital infrastructures, and a dynamic market for UAVs were strong enablers. However, strict airspace regulations, speed limits, mandatory registration, privacy concerns for the government, and uneven accessibility of training constrained practical UAV implementation.

Analysing integration across the wildfire emergency phases, findings revealed that UAV applications were predominantly reactive, focusing heavily on detection and response phases, with limited use in recovery phases, with further visual analysis in MAXQDA, which supported this imbalanced UAV application across all wildfire management stages.

In addition, themes such as interagency collaboration, advanced training standards, and secure privacy protection require attention for effective UAV integration for WEM. Emerging findings such as potential increasing cost due to 5km under airspace privatisation and count local knowledge for trajectory design are also valuable for consideration. These findings and insigts (see Table 5.4) set the stage for deeper interpretation and practical implications in Chapter 6 with existing literature and theoretical frameworks, drawing out broader implications for public sector innovation and disaster governance in China and beyond.

Table 5.4 Key theme findings and insights

TOE Dimension	**Sub-theme**	**Key Insight**	**Relevant WEM Phase(s)**
Technological	Battery limitations & signal instability	Short battery life and unstable signals in mountainous areas limit UAV performance	Detection, Suppression
	Payload flexibility & clustering potential	Enhance battery tech and drone clustering to overcome flight time limits	All Phases
	Mobility in remote area	Realise the principal of human life first	All phases
Organizational	Human resource training & skills gap	Lack of UAV-specific training hinders operational effectiveness; Gap between drill and real practice	Preparedness, Response

	Interagency coordination challenges	Fragmented coordination between phases reduce UAV deployment efficiency	All Phases
Environmental	Strict airspace and privacy regulations	Regulatory limits, privacy concerns, and mandatory flight approval constrain usage	Prevention, Detection
	Digital infrastructure and UAV market development	Supportive national policy and UAV market growth facilitate UAV availability	Procurement, Planning
Emerging Finding	Airspace privatization and restricted access	Private sector control of airspace poses cost barriers	Deployment
	Local knowledge in UAV route planning	Experienced local residents provide valuable input into adaptive drone trajectories	Detection, Route Planning

6 Discussion

This exploratory study aims to examine the practical challenges and opportunities resulting from the implementation of UAVs in WEM systems, using qualitative data collected in Sichuan Province, China. The inductive reasoning approach indicated new, context-specific insights and challenges in UAV deployment, while the deductive reasoning approach, applying the TOE framework and H-EMLC theory, allowed the interpretation of these findings within established theoretical frameworks. This chapter examines the principal findings from Chapter 5, comparing them with current literature, assessing the relevance of the selected theoretical frameworks, and emphasising the wider research implications and limitations. This integrated approach provides new insights into the ongoing debates for the integration of UAVs into WEM practice and contributes to the localisation of these frameworks by incorporating unique institutional and environmental factors in China.

The qualitative data underscored the benefits of UAVs in time and labour efficiency, personnel safety, and rapid response. The results were aligned with the findings of Partheepan, Sanati, and Hassan (2022), as well as the thoughts from Afghah et al. (2019) and Bailon-Ruiz, Bit-Monnot, & Lacroix (2022), who believed in the superiority of UAVs compared to conventional wildfire management methods such as patrol, watch tower, helicopter, etc. Especially, abilities in real-time monitoring and detection and high mobility in remote and hazardous terrains similarly reflect the benefits assessed by Boroujeni et al. (2024) and Bailon-Ruiz & Lacroix (2020). Besides, this study reaffirms the insights from Momeni and Mirzapour Al-e-Hashem's (2024) regarding the evolving role of UAVs, highlighting their increasing payload capabilities and their extension practice from passive data collection to active suppression and response actions. However, contrasting views from Lou et al. (2015), who expressed the payload limitations, highlight technological advancements over the past decade that may have rendered previous findings outdated. The findings also including the technical deficiencies, such as limited battery longevity and endurance, continue to be evident, reflecting the same concerns raised by Luo et al. (2019).

Participants suggested battery endurance improvement and developing alternative fuels like hydrogen, which resonated with Sun et al. (2023)'s proposals. Findings indicated that flight pre-scheduling, UAV cluster strategy, and integration with digital systems are essential technical elements that require both technological and organisational contributions. They were aligned with research by Khan, Gupta, and Gupta (2022), which emphasised the importance of optimising UAV trajectory design and flight planning, whereas Brust and Strimbu (2015) explored swarm models applicable for large-scale wildfire events. But how to effectively pre-design the trajectory and drone team depends on the organisation's capacity and local operation context, as well as the external digital infrastructure support. Additionally, the signal could be a barrier in the remote areas so that participants emphasise the importance of remote-area connectivity construction for data transfer and operation. This finding, aligned with Liu et al. (2023) who highlighted the importance of communication infrastructure, and Partheepan, Sanati, & Hassan (2022) emphasised the importance of signals for locating the target. This focus on the external digital and technical infrastructure also reflects the interconnection feature of the TOE framework. A notable new insight was the value of local knowledge in designing trajectories and UAV clustering strategies, which is an area underexplored in current literature but possibly complementary to social data integration (Luna & Pennock, 2018). As suggested in the findings, technically, for the UAV developers should focus on developing terrain-specific battery enhancement technologies and alternative battery fuel in the future. For WEM, organisations should improve the pre-scheduled route and drone team design, as well as improve the operators' personnel skills.

Having discussed the UAV adoption from the technical layers, the organisational elements are also crucial, including its capacity and readiness. The findings reflected the decision-making processes, investment priorities, sufficient funding and interagency coordination as essential components. This finding extends the thoughts of Tymstra et al. (2019) and Khan et al. (2023), who highlighted financial limitations but neglected the organisation's internal investment priorities and ability for self-reinforcement, but it is consistent with Calkin et al (2015) study that discussed institutional inertia and cost prioritisation. In Sichuan, there is sufficient state funding; however, the discretion in allocation and the orientation of leadership, as well as the conservative culture, influence UAV deployment, thereby further extending the framework proposed by Calkin et al. (2015). The qualitative data observed that UAVs require complementary infrastructure (e.g., data transmission systems, analysis platforms) and staff training programmes that exceed basic licensure requirements. This study emphasises the essential need for industry knowledge and interdisciplinary skill sets, in addition to the certified programmes and scenario simulations, which reinforces the proposal from Luo et al. (2019). The study contributes to the existing literature by highlighting the complex challenges associated with the integration of UAVs into the Chinese political and bureaucratic framework, which decides the organisation's decision-making process, investment priorities and training programme execution. In the end, findings suggested that the WEM organisations should establish centralised UAV training standards at the county level; improve the ability for self-reinforcement and multi-drone strategy design; enhance inter-agency collaboration models, as well as consider extending the UAVs' application beyond wildfire management to other disasters within the whole year to maximise its usability.

In addition, the external environmental factors also influenced the UAV's technical default and organisational operation, so when it comes to external environmental factors, which emerged as both enablers and barriers. The findings observed the regulations on flight speed and altitude restrictions and no-fly zones in China, which aligned with findings from Khan et al. (2022) and Luo et al. (2019), who also insisted that the regulation on the operation could hinder faster deployment of UAVs. Notably, a new observation on airspace privatisation in Sichuan Province suggests that rising operational costs may occur in the future, which is a point absent from current literature. Additionally, ecological disruptions (e.g., to bees and livestock) offered new insight into the social acceptance and environmental ethics of UAV operations. The study confirms the dual nature of regulatory practices: while ensuring privacy and data security, they may hinder responsiveness during emergencies, as emphasised by Luo et al. (2019). Data governance challenges brought by wider application of UAVs continue to be noteworthy, particularly related to privacy and unauthorised access. For instance, the procedures and regulations governing operation approval and certification for pilots hinder timely responses while ensuring legal and standardised operations. External digital technology ecosystems, including AI, RS, 5G, etc are regarded as vital complementary support to mitigate the limitations of UAVs, which supported research trends in this field proposed by Akhloufi et al. (2021), Keerthinathan et al. (2023), and Boroujeni et al. (2024). The national initiative for integrated “space–aerial–ground” platforms reinforces the conclusion that digital infrastructure is vital for UAV-WEM integration. Besides, the dynamic drones market also provides multiple types of drones for the WEM organisations for application, which also extends new insights on the external accessibility for wider adoption of UAVs.

Finally, the findings suggested that the government should clarify the regulatory framework and communication strategies for better data governance and privacy protection, as well as enhance the awareness of the public for UAV applications and wildfire prevention.

The findings confirmed the extensive integration of UAVs across wildfire emergency phases: preparedness and prevention, suppression, and recovery, but they demonstrated varying levels of effectiveness. This finding is consistent with H-EMLC theory regarding the predominance of the "during" phase. Nonetheless, prevention and recovery are frequently underutilised, supporting theoretical expectations that post-event phases are often overlooked, which aligns with the study by Boroujeni et al. (2024).

Findings reflected that UAVs can be applied in mapping and wildfire monitoring, while limitations such as funding delays and sparse patrol frequency hinder their effectiveness in prevention efforts. During active wildfires, UAVs perform optimally in ignition spot detection and terrain assessment, which corresponds to technological expectations and real-world deployment feedback. Suppression support through payload delivery and extinction is a newly emphasised function. However, in the recovery phase, the focus is on post-fire assessment and material transport. This underutilisation is consistent with Boroujeni et al. (2024)'s critiques that view recovery as a neglected domain. The study contributes to the discourse by promoting structured guidance and institutional mandates with regard to UAVs in ecological restoration.

In summary, the findings confirmed and extended existing literature and, in certain instances, challenged it while presenting new opportunities. Technological advancements have evolved beyond some earlier limitations, while organisational and environmental elements bring nuanced layers of complexity and interaction. In addition to established challenges, this study surfaced novel insights not yet widely addressed in the literature. These include growing concerns over provincial airspace privatization, which limits flexible UAV deployment in high-risk zones, and the emerging practice of incorporating local ranger knowledge into UAV route design and scheduling The effectiveness of integrating UAVs into the WEM system is not only dependent on technological maturity but also on adaptive governance, inter-agency coordination, and policy innovation. Therefore, this study situated the findings within the political and ecological context of

Sichuan, offering new insights into the global discussion on UAV implementation in emergency management.

7 Conclusion

This study mainly explored the UAV integration into China's WEM system with a case study site in Sichuan Province. The study was motivated by the increasing frequency and severity of wildfires and the growing trends in using advanced technologies to enhance disaster prevention and response capability. Through a qualitative, case study approach, this research collected and analysed data from interviews with UAV operators, UAV vendors, wildfire managers, and frontline patrol workers, as well as policy documents, regulations, and technical media reports.

7.1 Answer the research question

The literature review established that while UAVs have been widely recognised for their technical potential, such as real-time data collection and risk assessment, a strong tool for WEM decision-making and suppression task conduction, there remain significant challenges not only on the technical flaws, but also related to their organisational adoption with capability on structure reform, human resources skill improvement, cross agency coordination; and the external environment, including operation regulatory, data privacy concern, infrastructural factors. Using the TOE framework and H-EMLC theory, this thesis systematically categorised the technological strengths and limitations of UAVs, the organisational capabilities and barriers to their use, and the external environmental enablers and concerns.

Key findings show that UAVs have already contributed to improved situational awareness, early warning, and real-time monitoring in wildfire management. However, their widespread adoption is constrained by technical limitations (e.g., battery life, signal range), organisational inertia, and strict operation regulations. The integration of UAVs varies across the different phases of wildfire management, with most focus on detection and monitoring, and less on post-fire recovery. The research also highlights the importance of collaboration, training, and policy support for the effective deployment of UAVs in the WEM system. The findings demonstrates the research questions are answered as foo

- Sub-RQ1: UAVs offer crucial surveillance and transport capabilities, but technical limitations remain.

- Sub-RQ2: Organisational and regulatory hurdles significantly decide the UAV deployment.
- Sub-RQ3: UAV integration is most effective when clearly aligned to specific phases, particularly detection and suppression.

Therefore, the study results answer the main research question and its sub-questions. The study offers a holistic understanding of the opportunities and constraints surrounding UAV integration in different phases of WEM in the specific governance and geographic context of Sichuan Province.

7.2 Research implications

This study has several implications. Theoretically, it extends the application of the TOE framework and H-EMLC theory into a qualitative, China-specific emergency governance context, offering new insights into how these frameworks interact with local administrative structures. This study also surfaced under-researched issues such as airspace privatisation regulation fragmentation and the value of bottom-up local knowledge in UAV deployment. Whereas existing studies often adopt a simulation-driven or quantitative lens, this thesis demonstrates the value of stakeholder-based inquiry in capturing the socio-organisational aspects of technology adoption with a qualitative aspect. Practically, the research offers recommendations for emergency practitioners in Sichuan and similar wildfire-prone regions. These include investing in standardised training for UAV operators, clarifying role divisions between agencies for cross-coordination, and adopting drone cluster strategies that allow for flexibility across different wildfire phases. Policy-wise, the findings suggest that while technological capacity is expanding, the surrounding governance framework must evolve in parallel. Updating airspace regulations for WEM, defining inter-agency data sharing protocols for security, and addressing ethical guidelines for UAV design and operation are crucial steps toward fostering a sustainable and effective integration.

7.3 Research limitations and recommendations

As long as the research achieves the research objective and makes the expected contribution to extending the theme on UAV applications for WEM in China, as well as fills the research gap on the limited qualitative research on UAV integration, several research limitations remain.

Firstly, the qualitative data collection excluded the policy maker responsible for UAV regulation in WEM and the provincial level director of the WEM command centre, as well as the response team at a higher administrative level, due to time and authority limitations. Secondly, when assessing the external environmental factors that affect the integration ofs, they were not totally included, such as misinformation, social media data sources, etc. Thirdly, the case study selection on the representative mountainous area in China may limit the generalisability of findings to other regions. Additionally, the paralinguistic interpretation limitations should be noted because the interviews were conducted entirely in Chinese, with coding data and quotations subsequently translated into English. Although careful cross-checking was used to ensure translation accuracy, subtle nuances in phrasing or tone may have been lost, as well as the capture of non-verbal cues (e.g., intonation, pauses, and emotional expressions) being weaker during interviews. Lastly, the limitation also lies in the reliance on self-reported data from the government; while triangulation with official documents helped mitigate this, some accounts may reflect aspirational statements rather than actual practice. Future research could benefit from combining stakeholder interviews with real-time field observations or system usage logs to validate the operational narratives provided.

At the end, there are several recommendations for future researchers. First, a comparative study between multiple provinces could uncover how institutional and geographic differences shape UAV integration trajectories. Second, further exploration of citizen and community perspectives on UAV use in emergency contexts would help reveal social acceptance and trust concerns, particularly as the application area expands. Third, focus more on the challenges post-wildfire stage application of UAVs. Finally, future research could investigate the integration of UAVs in multi-hazard scenarios, such as landslides or floods, thereby broadening the technology's application more than in wildfire periods and deepening its relevance to comprehensive emergency management.

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Declaration of Authorship

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Appendix

A Appendix 1: Interviewees list

Interviewees	Organisation	Position	Form
A	City A WEM department	Ground patrol worker	Face-to-face
B	City B WEM department	Ground patrol worker	Online
C	City C WEM department	Mountain checkpoint station	Online
D	City D ** Town Forest Wildfire Emergency Management Center	Director	Online
E	E Autonomous Prefecture Wildfire Emergency Command Center	Member	Online
F	F Flying Defense of Plant Protection Co., Ltd.	Legal representative	Face-to-face
G	F Flying Defense of Plant Protection Co., Ltd.	UAVs operator/trainer	Face-to-face

B Appendix 2: Questionnaire for the interviewees

Brief introduction before the interview

Hello, I am a student majoring in Master of Public Sector Innovation and e-Governance from KU Leuven(Belgium), the University of Münster(Germany), and Tallinn University of Technology(Estonia). I am currently writing a final master's thesis on the integration of UAVs into the wildfire emergency management system in China. This interview aims to understand how UAVs are integrated into different phases of wildfire emergency management, focusing on challenges and opportunities from technological, organizational, and environmental aspects. The interview is strictly anonymous, and your responses will be used for academic research purposes only. I may contact you later to further inquire about your answers. Additionally, I will send you the final thesis report at the end of the defense.

UAV Operators

1. Please introduce yourself and describe your role in UAV operations.
2. How long have you been operating UAVs, and what types of wildfire management situations do you typically use them for? And could you share one specific example?
3. What tasks do UAVs help you perform in pre-emergency (prevention & preparedness), during-emergency (response), and post-emergency (recovery) phases?
4. From your experience, what are the key strengths and weaknesses of UAVs in these different phases?
5. What challenges have you faced in coordinating UAV operations with emergency response teams or government agencies? (e.g., delays, communication issues, or conflicting priorities?) and can you answer from(pre-during-, and post-wildfire phases) aspects?
6. How is information collected from UAVs shared with the decision-makers during wildfire management? Is the process effective?
7. What are the regulatory constraints affecting UAV operations in wildfire management? (e.g., airspace restrictions, licensing, permits)

8. Have you encountered any issues related to privacy concerns or ecological protection laws when using UAVs? What are the regulatory constraints affecting UAV operations in wildfire management? (e.g., airspace restrictions, licensing, permits)
9. Have you encountered any issues related to privacy concerns or ecological protection laws when using UAVs?
10. What improvements would you suggest for UAV technology to better support wildfire management?
11. How do you see the role of UAVs evolving in wildfire emergency management over the next five years?
12. Is there anything you want to add?

Patrol worker

1. Please introduce yourself and describe your role in wildfire prevention and monitoring.
2. How does your responsibility change during high-risk wildfire months (1-6 months)?
3. Does your community use UAVs in daily patrol work?

If YES:

- How has UAV usage changed your responsibilities in wildfire patrols?
- Compared to traditional patrol methods, what are the technical advantages and disadvantages of UAVs?
- Can you discuss any organizational changes that have occurred as a result of integrating UAV technology into your daily operations?

If NO:

- What are the main reasons why UAVs are not used in your patrol work? (e.g., lack of training license, cost, regulatory restrictions, organizational decisions, etc.)
- If UAVs were introduced, what support (such as training, policies, or organizational adjustments) would be necessary for successful integration into the current wildfire management system?
- Would you be willing to work with UAVs in the future? Why or why not?

- How do you communicate and coordinate between patrol workers and emergency teams?

4. How do you perceive the impact of UAVs on job roles within the community patrol, especially in terms of job security and task shifting?
5. How does local government policy affect the integration of UAVs into patrol work?
6. Are there any policy restrictions on using UAVs in your patrol areas?
7. How do you envision the future of community-based patrols evolving with the increasing use of UAV technology?
8. What role do you see for yourself and other ground patrol workers in wildfire emergency management (pre-, during-, and post-phases) as UAV technology continues to advance?
9. What training or support is needed to help patrol workers collaborate with UAV teams? Or help a patrol worker transfer their job responsibility?
10. Is there anything you want to add?

Wildfire Emergency Managers

1. Please introduce yourself and describe your role in wildfire emergency management.
2. How are UAVs currently integrated into your region's emergency management framework?
3. How effective are UAVs in each phase of wildfire management (pre-, during-, post-wildfire emergency)?
4. What technological improvements are needed to maximize UAV benefits in emergency management?
5. How do you think the emergency teams should collaborate with UAV operators(before, during, and after) wildfire incidents?
6. What organizational changes do you think were required to integrate UAVs?
7. What are the main legal or regulatory barriers affecting UAV deployment in different phases(before, during, after) of wildfire management? How does your department plan to overcome?

8. How does your department address public concerns regarding UAV usage in wildfire emergency operations?

9. How do you see UAVs evolving in national emergency management strategies over the next five years?

10. What additional government support would help improve UAV integration in wildfire emergency management?

11. What are your suggestions for improving UAV integration into wildfire emergency management systems?

12. Is there anything you want to add?

C Appendix 3: Code System (Source: MAXQDA)

Code System	Memo	Frequency
Code System		439
EMERGING THEMES	Any related and insightful thoughts or ideas from the interview and other documentation,which beyond the literature review and background	0
Unexpected Uses	Use for surprising or secondary UAV applications	11
Recommendations from Stakeholders	Stakeholder proposals for better technology, policy, or workflows.	0
Environmental Support	Any(policy , finacial, training etc.)support from the any level of government	22
Organisational Support	Any suggestion related to the WEM agency internal/ cross-organisation support (training, reform, cross department cooperation, financial, investment etc)	7
Local Knowledge and Voluntory Force	Local residents who also can be seen as one of the important force in WEM and potential UAVs application promotor	4
Technical Improvement	UAVs technical improvement(function, battery, flight distance, charger)	14
STAKEHOLDER INSIGHTS	Including the related grounp in UAVs application and stakeholder who has experience in WEM or currently working in WEM one of the phases	4
Ground Petrol Worker	Local level crew for dialy community mountainous area petrol for wildifre detection and monitoring	9
Technology Provider	The UAVs private sector providor, while they can have multi role the same time (vendor, trainer and operator)	1
UAVs Operator	Field-level users (pilots, technicians) discussing operation, deployment, and risks.	1
UAVs Vendor	Refers to commercial technology providers discussing UAV capabilities, support, or limits.	3
Wildfire Manager	Refers to insights from wildfire officers on strategy, coordination, or UAV use.	3

WILDFIRE MANAGEMENT PHASES	Divide the WEM into intuitive 3 (Preparedness/Mitigation, Response, Recovery)phases as the substructure to demonstrate where UAVs are being used or underutilized across wildfire management phases	0
Pre-Wildfire	Refers to early UAV surveillance, sensor data, or early warning roles, as well as other assistant prevention methods	25
During-Wildfire	Apply when discussing UAV use during active fire suppression.	34
Post-Wildfire	Refers to burn severity mapping, damage surveys, or reforestation tracking.	18
ENVIRONMENT	Any element from external the organisation and the UAVs, such as policies, regulations, public trust, data integration, privacy, culture,etc.	0
External Digital Environment	Refer to the whole tech ecosystem, e.g., satellite availability, remote sensing, 5G, AI, ML, data cloud, social media, or third-party data integration platforms.	13
Privacy and Ethical Consideration	Use when discussing surveillance, civil liberty concerns, or data governance.	0
Ethical Consideration	Any concern related to ethical, social development	5
Government Perspective	Any concerns on the government aspects(data, privacy, security, etc.)	5
Regulatory & Policy Environment	External regulation and policy elements either to promote the UAVs adoption or hinder its integration in WEM system	0
Compliance and License	Any references or regulation to formal UAV operation license, permits.	15
Ecosystem Protection Regulation	Challenges or converns from the ecological aspects which influence the adoption of UAVs	4
Policy Gaps / Legal Barriers	Unclear UAV zoning, restricted flight areas,Use when interviewees mention unclear, restrictive, or absent drone regulations.	19
Enabling Policies / Guidelines	Mentions of government willingness, public campaigns, or policy advocacy for UAVs. (drone flight approval mechanisms, provincial support)	13
Public Perception / Trust	Public fear, acceptance, or misinformation about UAV use in WEM.	0

Public complaint on WEM method	Any feedback or any mention on the negative antitude on the traditional or current WEM method, which reflect the importance of the reform in WEM with UAVs	7
Positive antitude to wide adoption of UAVs	Any support feeling or high expectation from the public	3
Hesitation in Adoption	Any feeling from the public that doubt the usibility and effectiveness of UAVs	3
ORGANIZATION	The aspect from the WEM organisation internal to support or hinder the wide adoption of UAVs in different phases of WM	0
Human Resoureces Training	Training gaps, technical knowledge, or availability of skilled UAV users. Training can be from the internal organisation or from the private sector	8
Lack of Training / Skill Gaps	Insufficient technical support, knowledge gaps	4
Job Content Change	Staffs' insights related to job change, job security, job task revert.	0
Job Task Transfer	Transfer the role in wildfire management	9
Job Security	Fear of losing job, fear of change job content	3
Training Availability & Capacity	Accessible courses, trained UAV pilots	2
Financial Management	Apply when funding, purchasing delays, or cost-effectiveness are discussed.	0
Financial Support / Enabling Policies	For sources mentioning lack of funds, high costs, unsustainable budgets, etc	7
Funding Barriers / Financial Limitations	For sources that report grants, subsidies, or state investment in UAVs	4
Organisational Capability	Indicate the ability to reform and adopt UAVs into the current techniques for wildfire management and ability to reorganisation, resource allocation and decision-making for the leader	7
Interagency Coordination	Mentions of collaboration or disconnect between fire, emergency, forestry departments, any cross department support, including data sharing, resources sharing, expert support...	39

	Operational Procedures and Structures	Use when protocols, SOPs, or response workflows, decision making on recruits, human resource reallocation are mentioned.	13
	Organizational Resistance or Culture	Hesitation or delayed attempt on institutional reform, new technology adoption, it can related to the leader thoughts, habits, local cultures....	7
TECHNOLOGY		Weaknesses like battery life, flight limits, or unstable signal.	1
Technical Advantages		Any strengthens in UAVs the technology itself and the benefits in the apllication of WEM, such as funtion, capabilty, application, market disclosure...	62
Technical Weakness		Any disadvantages in operation (battery, signal, playload...) , cooperation， adoption, limited application industry	27
	Weather Condition Restriction	Any constraints on weather condition(frog, rain, windy)	3
Paraphrased Segments			2

D Appendix 4: Interviews audio transcript in English

All interviews were conducted in Chinese, and transcripts were then translated into English for the convenience of readers. For anonymity and confidentiality, the identifier information of the participants has been omitted. The original Chinese text of selected key quotations in the final report is available from the author upon request.

Interviewee A

Interviewer: Hello, could you please introduce yourself and describe your role in forest and grassland fire prevention and monitoring?

Interviewee A: I am a resident of XX village in city A and a daily patrol worker. Because fires often happen in our village, our village chief organizes all residents to take turns patrolling the mountains from January to June every year.

Interviewer: Okay, in the high-risk months, for example, as you mentioned earlier, from January to June, how does your role change?

Interviewee A: Well, when it was my turn, I was, um, the inspector of the mountain pass. When it was not my turn, I was just an ordinary resident of the village.

Interviewer: Yes, sure. Do you use drones in your community for routine patrols? You can answer yes or no.

Interviewee A: Yes.

Interviewer : If so, how has the use of drones changed your duties on patrol?

Interviewee A: Well, the use of drones has allowed me to switch from patrolling the mountains manually to using drones to go into the mountains and patrol.

Interviewer: Compared with traditional ground patrols, what do you think are the advantages and disadvantages of drones?

Interviewee A: Well, first, the advantage is that it reduces the consumption of manpower. We don't have to spend so much manpower to patrol the mountains every day. This saves us time and improves our efficiency. The disadvantage of drones is that due to some irregular technical operations, the drones may have accidents and then fall into the mountains. We must send people to the mountains to find where the drones fell. And sometimes, because drones fly at a high altitude, we may not be able to find the small flames in the mountains in time. So when we find them, the fire may have been reduced.

Interviewer: So what you mean is that, uh, patrolling is a prevention phase, and fighting a fire is a response phase. Are these two meanings not very consistent?

Interviewee A: Yes, it is a two-step process.

Interviewer: Yes, it is indeed two steps. You mean that when the drone is patrolling and when the relevant departments come to put out the fire, they are not connected at this stage, right?

Interviewee A: Yes, um.

Interviewer: Okay. And then can you discuss, now that drone technology has been integrated into daily operations, what organizational changes have you observed? Any organizational changes that have occurred.

Interviewee A: What does organizational change refer to?

Interviewer: For example, have there been any changes in your internal patrol organizations or in the relevant departments of your community? Or have you seen any changes from the outside?

Interviewee A: I think there have been changes in our patrol team. For example, before there were no drones, we might have to patrol once every two weeks or so. But after using drones, our efficiency has increased, so the number of times each of us rotates has decreased. This solves the problem and gives us more personal time.

Interviewer: So how do you communicate and coordinate between patrol officers and emergency response teams physically and virtually?

Interviewee A: First, the patrol officers and the emergency response team must maintain contact every day, and the patrol officers of the day and the emergency response team of the day must be on stand by at all times.

Interviewer: Yes.

Interviewee A: First, let the patrol team go into the mountains to check if there is a wildfire. Then, if there is a fire, immediately call the emergency team to report the location, and let the emergency team come quickly to find the location of the wildfire and put out the fire urgently. If the fire is large, we need to contact 119 or other organizations to help us.

Interviewer: How do you think drones will affect the roles of people in community patrols, especially in terms of job security and task shifting? Well, I think drones still play a relatively important role, because, after all, they are... Well, there may be some translation problems in this area, that is, job security and task shifting, that is, whether you think your job will be lost, or the issue of the transformation of your job content.

Interviewee A: I think my job will definitely not be lost, because first of all, you need someone to operate the drone, so does that person still need to have this job? And when the drone finds the location of the fire, we still need someone to go to the Mars site to check the situation and see if there is indeed a fire? Still need a fire-fighting team to help, so I think these positions will not disappear.

Interviewer : Well, it’s just a change of job roles, right?

Interviewee A: Yes.

Interviewer: Well, okay, so how do you think local government policies affect the integration of drones into patrol work?

Interviewee A: Well, the local government's policies, for example, the government allocated funds to us to purchase and use drones and maintain unmanned drones, which reduced the economic pressure on our village or town, and also promoted the development of forest fire prevention in our area. The policies also gave us some financial subsidies, such as how much money you can get for patrolling for a day? In this way, for example, for those who have a difficult family economy, I think it does provide them with some job opportunities and financial support.

Interviewer: Do you find any policy restrictions on the use of drones in your patrol areas?

Interviewee A: Policy restrictions, for example, there are no-fly zones. Indeed, we still have to abide by the regulations for drones. For those places, we can only use manual patrols.

Interviewer: I would also like to know whether no-fly zones are generally notified in advance or you need to check the regional planning of no-fly zones yourself?

Interviewee A: Yes. This way you can check online in advance and know where you can't fly.

Interviewer : Well, what about suggestions for the future, for example, as the use of drone technology increases, how do you envision the future development of community patrols?

Interviewee A: I think if drones can be developed to be user-friendly in the future, we can eliminate the manual patrol mode and directly carry out patrol work at fixed points in an efficient and orderly manner without spending so much manpower and money. It will greatly facilitate our lives and provide a good guarantee for our forest fire prevention safety.

Interviewer: Then as drone technology continues to advance, what role do you think you and other ground patrol officers will play in forest and grassland fire emergency management?

Interviewee A: We will play the role of protecting the safety of residents living around the forest. We will use our own abilities to do our best to ensure the safety of the residents in our area.

Interviewer: Yes, what kind of training or support is needed to help your patrol officers collaborate with other drone teams? Or how to help patrol officers shift their job responsibilities?

Interviewee A: What we need is training on how to use drones and some precautions about drones, especially telling us which are the no-fly zones, because if you insist on no-fly zones, it will have a big impact. And, uh, uh, we also need to be told how to use drones to determine where there is a fire, where is safe, where is a dangerous place, and at the same time, we also need to be able to use drones to directly determine where the location is so that we can have an accurate longitude and latitude, etc., so that we can learn these basic knowledge.

Interviewee B

Interviewer: Please introduce yourself and describe your role in forest and grassland fire prevention and monitoring.

Interviewee B: Villagers of ** Village in B City work part-time as fire patrol officers. They carry loudspeakers and flags to promote fire prevention during their daily community patrol work.

Interviewer: How does your role change during the high-risk wildfire months (January-June)?

Interviewee B: My role hasn't changed much, because I'm not on patrol full-time. I just go when it's my turn, and the rest of the time I do my job.

Interviewer: Does your community use drones in daily patrol work?

Interviewee B Not used

Interviewer: What is the main reason why you do not use drones for patrol work? (e.g., lack of training certification, cost, regulatory restrictions, organizational decisions, etc.)

Interviewee B: First, there is no certificate of qualification. Second, my community has not introduced it, at least not in daily patrols. I don’t know if other departments have it. Third, they still use the old way, with community residents and militia patrolling.

Interviewer: If drones are introduced, what organizational support do you think is needed for successful integration (e.g., training, policies, or organizational adjustments)?

Interviewee B: First, financial support. Although human resources cost money, the purchase of equipment also requires investment. In addition, the regular fire prevention period is only half a year each year, so the cost investment issue may be considered. Second, policy support is also a problem. If the leadership is conservative and afraid of risks, it is difficult to introduce these high-tech products. Third, training is also a problem. There are very few training institutions in this area here, and if there are, it is not sure whether they are formal.

Interviewer: Would you be willing to use drones in the future? Why or why not?

Interviewee B: As for me, I am willing to do it, because it is indeed a trend. I also understand that our country is indeed leading the world in the development of drones, but it may take some time for our remote areas to achieve it. And it is indeed better than large-scale manpower investment. After all, April to June is the busy farming season, which is very tiring. I also have to patrol the mountains, which wastes time and is physically tiring. Moreover, it is a voluntary activity. Not everyone has the time to patrol the mountains. Moreover, if a fire is found, the source must be traced, which is a waste of time. If it goes wrong, I will also be held responsible, which will be very stressful.

Interviewer: How do you communicate and coordinate between patrol officers and emergency response teams?

Interviewee B: Our patrol officers are mainly responsible for daily patrols. If we find a fire source, we immediately report it to the village group for extinguishing. However, if it is a large fire, we report it to a higher-level emergency team, who will then make a decision on how to put it out. I mainly patrol the mountains and communicate mainly by phone, as well as record and report in writing.

Interviewer: How do you see drones impacting job roles in community patrol, particularly in terms of job security and task shifting?

Interviewee B: First of all, we will not have to mobilize so many residents to patrol the mountains, and the efficiency will be higher. It is definitely better than manual labor to obtain a large amount of forest area data in a short period of time, because we are still mainly patrolling in the mountains, and the terrain limits the speed. I don't think I will lose my job. I was originally a part-time task, not a main job of patrolling. I have my own land and income, and I don't just do this. If the task is transferred, it will indeed change. I patrol by walking and driving. If I am introduced, it is not necessary for everyone to know how to operate. Even if I am needed, I must learn how to operate it. Another thing seems to be that you need a certificate to work. And the arrangement of the areas that each person is responsible for is not up to me. I just change the way of patrolling the mountains. In fact, the nature is still the same, but the tools are different.

Interviewer: How do local government policies influence the integration of drones into patrol efforts?

Interviewee B: At present, we have not received any request from the government to replace all patrol work with drones. It should not have reached the stage of banning it. If there is a policy in this regard, grassroots personnel can only implement it. However, the county where I live does not have such a policy requirement.

Interviewer: Are there any policy restrictions on the use of drones in your patrol area? (e.g., certification, privacy, ecological protection, etc.)

Interviewee B: I don't know much about the specific policy restrictions, but I only know that there are no-fly zones in some places, such as near military areas, government agencies, etc., but there will usually be a sign saying it is a no-fly zone. This is government privacy. Other areas don't seem to be so strict. Certificates are also required, but the issuing agencies are not common, and it is not easy for ordinary people to obtain them. There doesn't seem to be much restriction on the use of drones in terms of ecological environment, and the energy consumption will not reach the amount of car emissions.

Interviewer: With the increasing use of drone technology, how do you envision the future of community forest-grassland fire patrols evolving?

Interviewee B: In the future, I think it is still necessary to popularize it, even in some remote mountainous areas. It is not necessarily applicable only in plain areas like the northeast, but also in mountainous areas. It is not necessarily only in developed areas. If you compare the long-term investment cost with the labor cost, I think it is more cost-effective and more cost-saving. It mainly replaces a large amount of manpower investment and saves time for patrol officers. The future community should be more advanced. These AI, drones, and 5G should be combined and applied to benefit ordinary people.

Interviewer: As drone technology continues to advance, what role do you think you and other ground patrol officers will play in the different stages of forest and grassland fire management (before, during, and after) ?

Interviewee B: In the early stage, we will definitely not need so many patrol officers. A small number will be enough. We can add some pilots, either professional pilots or patrol officers who have turned into professional pilots, to patrol and cooperate to protect the safety of communities and mountainous areas. If there is a responsibility, it is to assist emergency personnel, such as firefighters, militia, and volunteers. If a fire occurs, our locals are familiar with these mountains and can also serve as volunteers to provide help, such as which road is faster to climb the mountain, which road is suitable for rescue vehicles to climb the mountain, etc. In the later stage, we can only play an auxiliary support role in post-disaster recovery.

Interviewer: What training or support is needed to help patrol officers collaborate with drone teams or to help patrol officers shift their job responsibilities?

Interviewee B: Skill training, certificate acquisition training, I think training is one thing, but the actual operation still depends on the actual situation. The cooperation between the two sides is important, and the emergency rescue team and the leadership's command must be coordinated. If the patrol personnel want to transfer their job responsibilities, they still have to participate in professional vocational training, and it depends on their willingness. Unless you really want to change your job, you can participate in certificate training, which is not only useful for fire prevention, but also for other disasters.

Interviewer: Do you have anything else to add?

Interviewee B: No.

Interviewee C

Interviewer: Please introduce yourself and describe your role in forest and grassland fire prevention and monitoring.

Interviewee C: I am a villager from ** Street around C City. My main job is to register the information of people and vehicles at the intersections leading into the mountains, and to inspect and confiscate fire sources.

Interviewer: How does your role change during the high-risk wildfire months (January-June)?

Interviewee C: From January to June, I took turns with the volunteer militia and the people in the same group to register the information of people and vehicles entering the mountain, including name, phone number, ID card, license plate number, time of entry, signature confirmation, etc. If they have matches or lighters, they are required to hand them in. Then there are some statistics on the day's entry into the mountain and fire monitoring. There is not much change, unless there is a fire that needs to be reported immediately, extinguished, and the people involved are checked. The fire prevention period is over, the checkpoints are cancelled, and there is no need to guard the checkpoints.

Interviewer: Does your community use drones in daily patrol work ?

Interviewee C: No

Interviewer: What is the primary reason why you do not use drones for patrol operations? (e.g., lack of training certification, cost, regulatory restrictions, organizational decisions, etc.)

Interviewee C: There are no machines to replace people for the time being, because we need to confirm the information of visitors, explain the purpose of the checkpoints to people, and then take turns. Someone has to check whether vehicles and people are carrying fire into the forest, including those who go to the mountains to quench wild fires. Their tools must be discovered in time and then dissuaded. This is mainly to prevent fire from entering the mountains at the source. Then there are other people who patrol on a daily basis. The drones you mentioned have not been used yet. There are drones for spraying pesticides and watering, but they have not been found during patrols.

Interviewer: If drones are introduced, what organizational support do you think will be needed for successful integration (e.g., training, policies, or organizational adjustments)?

Interviewee C: Policy support, anyway, so far this year, it is still the same way. The state has said how to prevent fires, and there is still no policy change. Organizational adjustments are definitely necessary. After all, now it is arranged by the local grassroots villages themselves, and it is uncertain how personnel adjustments will be made later.

Interviewer: Would you be willing to use drones in the future? Why or why not?

Interviewee C: I am still willing to do it in the future, because it is still hard to guard the checkpoints in shifts, especially for those who work the night shift. In fact, it is still tiring, and some people don't understand. They are told that they are not allowed to light fires and cook or smoke in the mountains. Others don't understand when they come, saying that their privacy is violated and their personal information is required. There are also many complaints. There is nothing we can do about it. The regulations are like this. Many tourists drive here and need to be checked and registered, but people just don't understand. If there are drones, they can check images even if they enter the mountains, and hot spots can be discovered in time, but there still needs to be some resident drones for daily uninterrupted patrols. Then the experience of people entering the mountains will be better, and there will be fewer concerns, especially for tourists from other places.

Interviewer: How do you communicate and coordinate between patrol officers and emergency response teams ?

Interviewee C: I am a checkpoint personnel. I have all the patrol personnel's information here. I let them pass and register them. I actually communicate with them every time I am here on patrol. If there is a fire, they must report it to the village or team immediately. Then the firefighters will come, even if it is a small fire. The checkpoint does not block the emergency team, but they need to provide all the data we have about entering the mountain.

Interviewer: How do you see drones impacting job roles in community patrol, particularly in terms of job security and task shifting ?

Interviewee C: I think the composition of community patrol personnel will change. For example, before, local people were patrolling. As for drone operators, they will still replace the original patrol personnel. They should not lose their jobs. After all, the fire prevention period in this place is only half a year, and we have nothing to do in the other half a year. Moreover, they are all scheduled. If they are not on the schedule, they can do their own work. Of course, the tasks should be changed. I think there can be fewer people at the checkpoints, because before, our checkpoints were strictly for patrol personnel, and the emergency personnel reduced their workload, although the method was simpler. Then the fire department is still the same, the patrol personnel are the same, including our checkpoints, they are all the same work, but we don't need to arrange so many people.

Interviewer: How do local government policies influence the integration of drones into patrol efforts ?

Interviewee C: I think the use of drones is still determined by local policies. Although we have not yet issued a policy requiring our mountain patrol and checkpoint personnel to use drones or other monitoring technologies, if there is a policy requiring their use, they will definitely be strictly implemented.

Interviewer: Are there any policy restrictions on the use of drones in your patrol area ? (e.g., certification , privacy, ecological protection, etc.)

Interviewee C: At present, I haven't found any policy restrictions. The mountains around the county are all connected to residents, scenic spots and villas. I haven't found any prohibition on flying drones. There are also some tourism promotional videos and some tourists who use drones to take pictures. I haven't found any prohibition on using them. There is no strict restriction on flying. As for certificates, there should be restrictions on use. And there are no strict restrictions on ecological protection and the like.

Interviewer: With the increasing use of drone technology, how do you envision the future of community forest-grassland fire patrols evolving ?

Interviewee C: I think that in the future, with the increased use of drones, the number of ground personnel required for patrols will definitely be reduced, both in terms of number of people and frequency. Then there is the issue of setting up checkpoints. With uninterrupted aerial patrols, checkpoint inspections may not be necessary, and the standards for entering the mountains during the fire prevention period will not be so strict.

Interviewer: As drone technology continues to advance, what role do you think you and other ground patrol officers will play in the different stages of forest and grassland fire management (before, during, and after)?

Interviewee C: In the early stage, we still help each other. Our role is to reduce the occurrence of human factors. For example, we check the source of fire and publicize fire prevention policies. In fact, we also help them prevent fires. If a fire occurs, we are familiar with the forest area we are responsible for and can provide some basic information. In the later stage, we can also help with tree planting and restoration. After all, we are all in the same community.

Interviewer: What training or support is needed to help patrol officers collaborate with drone teams or to help patrol officers shift their job responsibilities?

Interviewee C: The arrangement of personnel, such as who will attend the training, who will patrol at what time, and the division of labor in patrolling areas, all need to be coordinated, and these are all the contents that need to be trained. Then there are patrol personnel, and the change of work content of checkpoint personnel also requires professional training.

Interviewer: Do you have anything else to add ?

Interviewee C: there is none left

Interviewee D

Interviewer: Please introduce yourself and describe your role in forest and grassland fire emergency management.

Interviewee D: I am the director of the Forest Fire Emergency Management Center of ** Town, D City. My responsibilities are to manage and coordinate the forest fire emergency management at the township (village) level, the communication and coordination of emergency management at the same level, as well as the monitoring and prevention of fires, and the handling and reporting decisions based on the fire level when a fire is discovered.

Interviewer: How do drones currently fit into emergency management systems for bushfires in your area?

Interviewee D: Drones are currently used in small quantities in the forest areas, scenic spots, and urban areas under my jurisdiction for fire monitoring, patrol, and emergency response. They are used in daily forest patrols and at the scenes of various disasters and accidents to provide support and coordination, but they are not fully put into use.

Interviewer: What is the role of drones in different stages of forest and grassland fire emergency management (early warning, response, and recovery)?

Interviewee D: The early warning stage mainly assists manual ground patrols. In a few extremely remote and rugged areas, domestic small drones are routinely deployed for flight. The response stage mainly involves extremely fast acquisition of high-altitude data on fire conditions and terrain, which enables the distribution of forces and command force decision-making analysis before the arrival of the subsequent rescue team, and synchronization of real-time extinguishing data with the command center. In the recovery stage, it is currently still combined with manual work to achieve the goal of zero hot spots after the disaster and we don't know how the post recovery information was published to the public.

Interviewer: In order to maximize the benefits of drones in forest and grassland fire emergency management, in what areas are technological improvements needed?

Interviewee D: There are issues of endurance and collaboration, especially the endurance of small drones needs to be improved, but it is OK to collect data in the short term, and the long-term endurance may not be ideal. Another issue is collaboration, which mainly lies in the distributed collaboration between drones, such as how to arrange and combine, communication between operators, and data acquisition requests from the command post. On the other hand, the collaboration between cargo-carrying drones and helicopters needs some improvement, including the data synchronization between different models and brands.

Interviewer: How do emergency response teams collaborate with drone operators before, during, and after a wildfire incident?

Interviewee D: In the early stage, the focus was on monitoring and preparation. Drone operators mainly collected information on terrain, vegetation, roads, villages, water sources, etc., which served as a reference for the emergency team to make decisions. For the annual planned burning operations, drones also have fixed planned autonomous inspection routes, as well as irregular all-weather operations to monitor the burning areas.

Once a fire occurs, firefighters will use drones to locate and report the fire immediately. The fire point data, including but not limited to the location of the fire line, the spread of the fire, water sources, vegetation information, and protected buildings, will be transmitted to the command center of the emergency team. This will enable the firefighters to quickly collect data before the rescue team arrives to support rapid and scientific command decisions. Ground personnel can immediately handle the fire and eliminate potential fire hazards. This will increase the frequency and efficiency of fire inspections and quickly and accurately identify fire sources.

In the later stage, hotspot detection includes locating abnormal high temperature points, monitoring thermal imaging at night, eliminating the potential threat of underground fires, alleviating the pressure of forest and grassland fire prevention, and reducing the potential risk of forest fires. Assist and report the overall data to the superiors, because the requirement is a zero-hotspot firefighting policy. The emergency team and the patrol team need to ensure that there are no new fire points before the entire incident is considered to be handled. These tools are on standby all day and support the operations of the fire brigade at any time. Then, the data before and after the disaster are pushed to the relevant units through the natural resources satellite remote sensing cloud service platform. This is not simply relying on manual data collection or data collected by drones, because it is currently a coordinated collection of satellite remote sensing, drones, and ground personnel data.

Interviewer: What organizational adjustments do you think should be made to adapt to drone technology?

Interviewee D: Who should be responsible for the relevant skills training and standardization of internal personnel, and whether to introduce relevant experts are all things that need to be considered. It also takes time to obtain a drone operating license. How to adjust the original rescue procedures and collaboration in a short period of time while keeping the organizational structure unchanged in the short term is also something that needs to be considered. How one fire case and one group collaborate and make decisions is a reflection of the organization's capabilities. Another thing is the gap between simulated rescue and actual operations after adding drones. How to flexibly and efficiently deal with uncertain actual operations is a certain challenge to the capabilities of internal personnel and decision-makers in the organization. In general, it is still necessary to enhance the flexibility and resilience of the organization to remain unchanged in the face of changes.

Interviewer: What are the main regulatory and policy barriers that impact the different stages of drone deployment for forest fire management (before, during and after)? What is your department’s approach to this?

Interviewee D: The main obstacles in the early, middle and late stages are still related to the restrictions of the no-fly zone. Because we are located in a mountainous area, the terrain is limited. Many places and time periods are no-fly zones. If the operator does not understand or makes mistakes, it is difficult to further deploy drones. Then there is the issue of licenses. There are very few training institutions in the local area, and licenses can only be obtained in provincial cities, which is a challenge for pilots to increase time and money. But this is not a big obstacle, after all, it requires norms and standards. Another is the impact of planned burning in the prevention stage on local air quality. We have received many complaints and complaints from the public. Our department's response plan is mainly to invite a large third-party organization with long-term operating experience in our local area to conduct training and popularization, including but not limited to our internal personnel, and some veterans have also received training. Then the relevant planned burning information is publicly released to reduce public panic and increase transparency.

Interviewer: How does your department handle public concern about drone use?

Interviewee D: This is also a big challenge, because the current industrial transformation is all about tourism. Tourists want to visit scenic spots in mountainous areas, but during the fire prevention period, the requirements for mountain entry inspection and scenic spot fire prevention are relatively strict. The online feedback received in this regard is not very good. The public is still relatively supportive of using drones for daily monitoring and inspection in mountainous areas. There has been attention and response to online public opinion, such as ground patrol policies, registration of fire inspections for entering the mountains, and limited number of vehicles entering the mountains, which are all publicized on relevant social media accounts and entrances to the mountains.

Interviewer: How do you see drones evolving in the national forest fire emergency management strategy over the next five years?

Interviewee D: I believe that the application of drones will become more and more extensive. On the one hand, there is policy support, which advocates the use of domestic technology products. On the other hand, there is financial support. Every year, the state provides a lot of support for forest fires in Sichuan. On the one hand, domestic drones, such as DJI, are becoming more and more mature. They are not only used for fire data acquisition and monitoring, but also have models that can carry fire-fighting materials. There are more and more pilots who meet the flight conditions. I believe that they will be used more and more widely. As a supplementary force for traditional forest and grassland fire emergency management, it provides strong power for intelligent and scientific management and assists emergency teams to minimize fire threats and hidden dangers.

Interviewer: What support should the government provide in the future to improve the integration of drones in forest fire emergency management?

Interviewee D: More popularization of basic knowledge of fire, increase public awareness of factors causing wildfire disasters, reduce the number of fires caused by human factors, and strictly implement preventive biological measures to reduce disasters caused by natural environmental factors and save emergency resources. Of course, I think this aspect is already very good. Publicity and education are popularized at the grassroots level, including short videos, text messages, banners and other means; there are also planned burning, afforestation, and the implementation of the red line of cultivated land. Another is the support of personnel training. I hope there will be more support from professional training teams. Of course, it takes time to form such a team. So in general, it is not a single support from one aspect, such as policy and finance, but the interaction of multiple aspects to improve the integration.

Interviewer: What suggestions do you have for improving the integration of drones into forest fire emergency management systems?

Interviewee D: My suggestion is still as mentioned just now, it is not the development and maturity of a single technology, but the combined achievements of multiple aspects that can better improve the integration of drones. It cannot be completed overnight. The policy call response and implementation of emergency departments at all levels, cross-departmental cooperation and coordination, the formulation and implementation of emergency plans, the resolution of conflicts between local economic development and strict fire prevention measures, public attention, personnel training, resource allocation, etc. all need to be taken into consideration.

Interviewer: Do you have anything else to add?

Interviewee D: No.

Interviewee E

Interviewer: Please introduce yourself and describe your role in forest and grassland fire emergency management .

Interviewee E: I am one of the main members of the E Autonomous Prefecture Temporary Forest and Grassland Fire Emergency Management Command Center. My duty is to manage and supervise the arrangements and issuance of ground patrol personnel.

Interviewer: How are drones currently integrated into the emergency management system for forest and grassland fires in your area ?

Interviewee E: At present, the use of drones in my area is not widespread. The main application is in agriculture. The fire emergency team mainly uses them for emergency management of forest and grassland fires. In the early stage, our daily patrols and daily forest data acquisition still rely on manual and remote sensing satellites.

Interviewer: What is the role of drones in different stages of forest and grassland fire emergency management (early warning, response, and recovery) ?

Interviewee E: In terms of early warning, it is still the monitoring of fire points and smoke points. It is easier to detect small fires in the forest area than manual patrols, but it is generally coordinated with meteorological warnings and national regional warnings. In terms of response, it is mainly used by fire emergency. In the recovery stage, if I understand correctly, it is the subsequent restoration of the forest area. In this area, we can also see whether there are any re-ignition points in the short term, secondary disasters, loss estimates, subsequent recovery plans, etc.

Interviewer: In order to maximize the benefits of drones in forest and grassland fire emergency management, in what areas are technological improvements needed ?

Interviewee E: The simplicity of operation allows more patrol personnel and ordinary people to master it quickly, and its battery life is enhanced.

Interviewer: How do emergency response teams collaborate with drone operators before, during, and after a wildfire incident ?

Interviewee E: In the early stage, it is still a preparatory warning. In fact, in layman's terms, during the annual fire prevention period, our ordinary patrol personnel should also belong to the emergency team, but they are not so-called firefighters. In the early stage, the drone operator needs to connect with the emergency team, such as the connection and cooperation of the corresponding area and time period. The operator can immediately connect the data of the fire point to the internal emergency response, and then their internal fire personnel can also arrange personnel to form a drone operation team. Of course, it is just a hypothesis. If a fire occurs, when extinguishing it, the drone operator can assist the emergency personnel in obtaining fire scene information, helping them how to allocate rescue personnel and extinguish the order. Including the news in the past few years, you can see that the rescue personnel did not have time to react and escape because the fire was too big and the wind direction changed suddenly. Then in the later stage, it is to assist in looking at the loss area. Of course, this estimation is not only based on the drone operator and the fire department, but also involves other departments in their own evaluation.

Interviewer: What organizational adjustments do you think should be made to adapt to drone technology ?

Interviewee E: If it is internal, it may involve personnel changes, such as new recruitment personnel, new personnel management standards, performance evaluation standards, new employee education and training, etc. Then there are organizational communication adjustments and notifications that need to be changed.

Interviewer: What are the main regulatory and policy barriers that impact the different stages of drone deployment for forest fire management (before, during and after)? What is your department's approach to this ?

Interviewee E: I think no matter which stage it is, we should still look at the latest notices from the Central Emergency Management Department and provincial governments to see what the emergency plans are. If there is no change, we should continue with the current approach. If there is indeed a notice, we should respond according to the relevant requirements.

Interviewer: How does your department handle public concern about drone use ?

Interviewee E: We have indeed noticed some suggestions from online public opinion on forest and grassland fire management. When encountering such situations, we always respond truthfully according to our internal policies and regulations. The general response channel is the local government website.

Interviewer: How do you see drones evolving in the national forest fire emergency management strategy over the next five years ?

Interviewee E: In the next five years, I think the application will be more extensive. I know that some areas have already been put into use, but there are more successful cases involving the assistance of private enterprises. Moreover, it is not just to obtain fire conditions from the air, some are equipped with fire-fighting materials, such as high-rise fires, to ensure the safety of personnel and property and efficiency. There is great potential here. Then there are also some new technical means, remote sensing, AI, etc., which can be combined and used, but it still takes time to implement them in each grassroots community.

Interviewer: What support should the government provide in the future to improve the integration of drones in forest fire emergency management ?

Interviewee E: I think that at present, the government has actually provided a lot of financial support at the state and county levels, and it can continue to provide such support in the future, but the use of funds will change. For example, equipment procurement, data platform construction, and personnel training all require huge investments.

Interviewer: What suggestions do you have for improving the integration of drones into forest fire emergency management systems ?

Interviewee E: I think we should learn more from advanced and successful experiences. I know that the Greater Khingan Range in Northeast China is already very mature in this regard. Although they are mostly plains, we can still learn from their model and learn from their experience in protecting forest resources.

Interviewer: Do you have anything else to add?

Interviewee E: there is none left

Interviewee F

Interviewer: Please introduce yourself and describe your role in drone operations.

Interviewee F: I am the legal representative of F Plant Protection Technology Co., Ltd. Our company is mainly engaged in drone training, drone sales, and drone transportation, involving agriculture, fire fighting, pesticide spraying, etc.

Interviewer: How long have you been operating drones? In what forest and grassland fire management scenarios do you typically use drones? Can you share a specific example?

Interviewee F: I have been in this industry for four years. I have used drones for firefighting, transportation, fire prevention, small fires, and fires in remote mountainous areas. For example, in some remote mountainous areas where vehicles cannot reach, drones can transport water to put out fires.

Interviewer: What role can drones play in forest and grassland fire prevention (early warning and preparation), emergency response and post-disaster recovery?

Interviewee F: For early warning and preparation, there are high-altitude patrols. For emergency response, the fire department will dispatch water and rescue supplies. For post-disaster recovery, it will also assist in the transportation of saplings, water, materials, etc.

Interviewer: From a technical perspective, what are the main advantages and disadvantages of drones at these different stages?

Interviewee F: From a technical perspective,

The advantage is

1. Saving time and labor costs is certain
2. The load capacity is a bit light. Conventionally, the T60 load capacity is 50kg, and the T100 load capacity is 75kg. However, the downward pressure wind field is large, which can easily damage vegetation. But in fact, the load capacity of 50kg is appropriate.
3. It can reach fire points that cannot be reached by vehicles. Compared with the situation where vehicles cannot reach the fire point and can only wait for the fire point to reach the boundary before extinguishing the fire, multiple drones can transport water to extinguish the fire at the same time, which is more effective than traditional methods.

4. It can fly over obstacles during the day and fly autonomously at night, saving at least 10-20% of manpower, material and financial resources.

Disadvantages:

Battery life: In hilly areas, the battery runs out of power after about 1km of flight. If you exceed this distance, you must return immediately, otherwise it will automatically land.

Signal problem: If the remote controller and the drone are too far apart, the signal will be lost, and the drone will not be able to be controlled and may fall.

Battery loss:

High charging cost: Charging requires fuel, which costs about 6-8 RMB per piece.

It is not widely used, only in agriculture, forestry and animal husbandry. The evaluation is mixed, some say it is good, some say it is not.

The cost of forest fire prevention is very high. For example, a government department invited our company to assist, but the charging cost was too high and we could hardly make any money, so there was no further cooperation or expansion.

The market competition is fierce, and the price competition is also fierce, with prices being pushed down.

Interviewer: What challenges have you encountered in coordinating drone operations with emergency response teams or government agencies? Can you answer from the perspective of different stages? (e.g. communication issues, limited authority, lack of coordination)

Interviewee F: In the early stage, it is still a docking problem. As mentioned earlier, as a private enterprise, you can't make money by docking and cooperating with emergency response teams or government agencies. In terms of company revenue, they are unwilling to take such orders. What we are doing now is the popularization and training of retired soldiers. I think it belongs to the early preparation stage. Authority is also a problem. At present, this business is still being done by the emergency department. It is in a monopoly, or it is within their scope of responsibility. It is difficult for private enterprises to intervene.

In the later stage, there are the same problems as in the previous stage. Unless there is a need, private enterprises cannot undertake this kind of business.

Interviewer: How can information collected by drones be integrated into the decision-making process for forest and grassland fire management?

Interviewee F: As I mentioned earlier, it is a question of authority. Only when the government departments over there have a need, we will have the possibility of cooperation or collaboration. Then the collected data will either be used for publicity, or to help rescue workers transport supplies to the mountain during the response phase. Plan the route up the mountain, etc.

Interviewer: What are the main operational regulatory limitations you encounter when using drones in bushfire emergency management? (e.g. airspace control, permits, approval processes)

Interviewee F: Yes, for example, the country strongly supports the low-altitude economy, but the low-altitude flight limits here have been bought out by private companies. They have investment vision and have bought out the routes below 5km before. So in the future, you have to pay to fly drones, and the purchase and sale of each drone must be registered with the Public Security Bureau and the Agricultural Bureau. If you don't register, it will be confiscated directly, even if you have insurance.

Interviewer: Have you encountered any challenges with privacy issues or ecological regulations when using drones?

Interviewee F: Yes. For example, there are reservoirs in rural areas. Some are used for fish farming, and some are used as drinking water reservoirs. Then there are bees in the flying area, which may be wild or fed. When they are in action, there will be residents to remind them to stay away.

Interviewer: In what aspects do you think drone technology needs to be improved to better support forest and grassland fire emergency management?

Interviewee F: The battery life could be longer. Although the four well-known DJI, JiMu, JiFei, and TuoGong models on the market are not good enough, There is nothing that can be improved in the load capacity. The current load capacity can already meet different practical needs. For example, if 250kg can be transported, but there is also great damage to the materials, then a load capacity of 50kg is actually enough.

The charging method has been improved, and it must be fully powered, such as a pure oil engine. For example, we used to have a fuel engine, and the explosion problem of the drone falling, after burning, only a steel frame was left, but the electric one, as long as the position is not high, it is possible to repair it. If it is a pure oil engine, there is no possibility of repair, and the battery is also burned out and cannot be repaired.

Interviewer: How do you see the development trend of drones in forest fire emergency management in the next five years?

Interviewee F: Not to mention other places, if it comes to my place within five years, I think we should have developed something like a vehicle, with every household having one. It is really practical, especially in the fields of agriculture, forestry and animal husbandry. Your patrols are restricted by time and terrain. For example, it takes you one day to patrol an area, but a drone can complete it in 20 minutes.

Interviewer: Do you have anything to add?

Interviewee F: In this regard, I think the country should be more responsible in training drone pilots, not just learning parameters during the exam, and then teaching them how to ascend, land, and fly left and right. They cannot learn the real application technology if they do not learn the supporting knowledge. But now, no matter which platform, the training of pilots does not teach basic application knowledge. For example, for forest and grassland fires, you must at least have basic knowledge, taboos, laws, and basic common sense. No matter what industry you are in, agriculture, forestry, and animal husbandry, you must learn it. Otherwise, the public's understanding of drones is also problematic. When it comes to application, they may refuse. Both theory and practice require training, but this also increases the cost of our training platform, and few platforms are willing to do it.

Interviewee G

Interviewer: Please introduce yourself and describe your role in drone operations.

Interviewee G: I am the one of the trainer in F Plant Protection Technology Co., Ltd. Our company is mainly engaged in drone training, drone sales, and drone transportation, involving agriculture, fire fighting, etc. My job is provide pilots training for the license and I am also an UAV operator.

Interviewer: How long have you been operating drones? In what forest and grassland fire management scenarios do you typically use drones? Can you share a specific example?

Interviewee G: I have been in this industry for three years and have used drones for aerial defense, transportation, fire prevention, small fires, and fires in remote mountainous areas.

Interviewer: What role can drones play in forest and grassland fire prevention (early warning and preparation), emergency response and post-disaster recovery?

Interviewee G: For early warning and preparation, or high-altitude patrol, for emergency response, the fire department will dispatch water sources. For example, if a small fire occurs, 50kg of water can be sprayed in two minutes. For fire reconnaissance, rescue materials, and post-disaster recovery, drones are also used to assist in the dispatch of saplings, water sources, materials, etc. For example, the mountains in Tibet are full of rocks, so after the disaster, saplings and soil are transported.

Interviewer: From a technical perspective, what are the main advantages and disadvantages of drones at these different stages?

Interviewee G: In terms of advantages, if we compare manpower and drones, it saves labor costs and improves work efficiency. For example, the same task may take a whole morning for a manpower, but I can complete it in 20 minutes with a drone. In terms of disadvantages, the current shortcoming of drones is that medium-sized drones have poor endurance and a short flight time.

Interviewer: What challenges have you encountered in coordinating drone operations with emergency response teams or government agencies? Can you answer from the perspective of different stages? (e.g. communication issues, limited authority, lack of coordination)

Interviewee G: I don't have much emergency experience. If the drone cooperates with the emergency team, the drone's operating route is very important and needs to be planned in advance. Airspace control must be applied for in advance. If there is insufficient coordination, there is a no-fly zone in a small area, but it is in the activity area. If the coordination is not good, other units involved will intervene.

Interviewer: How can information collected by drones be integrated into the decision-making process for forest and grassland fire management?

Interviewee G: First, help emergency teams open up rescue routes. Second, assist in the transportation of materials. Third, assess the losses. Also, coordinate the command at different levels and obtain early warning information.

Interviewer: What are the main operational regulatory limitations you encounter when using drones in bushfire emergency management? (e.g. airspace control, permits, approval processes)

Interviewee G: At present, speed limits and air restrictions are stipulated by national laws. There are airspace restrictions on flight speed and altitude. The first version for agriculture is 30 meters. Then the restrictions for different types and fields are different. Aerial photography and drones are different. The applications of the three major sectors of agriculture, forestry and animal husbandry are all different. For example, fire warning and prevention are now being carried out.

Interviewer: Have you encountered any challenges with privacy issues or ecological regulations when using drones?

Interviewee G: Ecological protection: Currently, in agriculture, there are generally restricted types of pesticides that cannot be used. There is no privacy protection for the time being.

Interviewer: In what aspects do you think drone technology needs to be improved to better support forest and grassland fire emergency management?

Interviewee G: Technically, the battery life is currently limited to half an hour. If the battery life is long, it will save costs. Now, if the oil cost is 6-8 yuan, it takes 10 minutes to fully charge a battery, such as DJI. The battery life and lifespan are both very important.

Interviewer: How do you see the development trend of drones in forest fire emergency management in the next five years?

Interviewee G: In the future, the development and promotion of forest management bureaus and emergency management bureaus will be in the areas of early warning and response. If drones are used for supervision and control, fire detection and fire handling will be faster and more efficient. Drones should cooperate with ground informatization to do this monitoring. As long as the government pays attention to this, there will be a very good development trend. Because at present, the government of the whole country is paying great attention to the problem of forest and grassland fires. For example, the major fires that occurred in the past two years, Xichang and Muli are repairing forest fire prevention passages and checkpoints to avoid the tragedy of such major fires. If it is to be developed, it is still led by the government and coordinated with various measures to give full play to the benefits of drones.

Interviewer: Do you have anything to add?

Interviewee G: The application of drones is still in its early stages, and will certainly be more widespread in the future. As the population ages, fewer and fewer people are engaged in these physical labor and this industry. Drones can alleviate this employment pressure to a certain extent. Drones can replace a lot of labor costs. In terms of trends, in addition to popularization, there are more urban and rural planning, such as smart logistics, air routes, etc. For example, now there are traffic jams on the road, and transportation is a problem. The pressure on air transportation is much less. In addition, many technology companies are promoting it, but the application in the main military field is more prominent now, but the development of other industries needs to be accumulated slowly.