Adoption and Use of Drones in Volunteer Fire Brigades: A Sociotechnical Analysis in the Context of Austrian Crisis and Disaster Management

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ABSTRACT

Unmanned aerial vehicles (UAVs, "drones") are increasingly used in crisis and disaster management for situational awareness, search and rescue, infrastructure assessment, and response coordination. Their integration into crisis and disaster management organizations is not only technical but also organizational and sociotechnical, shaped by regulation, training, authority structures, and resources. This paper examines drone deployment in Austrian fire brigades through a sociotechnical systems lens, comparing professional and volunteer structures. Based on semi-structured interviews and focus groups, it shows that deployment is shaped less by technology itself than by alarm models, legal frameworks, personnel availability, training, and interpersonal trust. Professional brigades benefit from stable staffing, while volunteer brigades rely more on flexible coordination and sustained training. The study highlights that resources are not only material but also relational and cultural in volunteer-based civil protection systems. Data collection will continue until June 2026, enabling presentation of first empirical insights at ISCRAM 2026.

Keywords

Drones, Volunteers, Sociotechnical systems, Fire brigades, Disaster management

INTRODUCTION

Unmanned aerial vehicles (UAVs, "drones") have become an increasingly important resource in crisis and disaster management, supporting situational awareness, search-and-rescue, infrastructure assessment, and coordination of response efforts. For emergency services facing rising demand through more frequent climate-related events, and persistent resource constraints, drones are often presented as efficient, cost-effective tools that can extend human reach without the external (expensive) support of helicopters or planes, broaden situational awareness, and reduce responder risk. At the same time, their integration into existing practices is not simply a technical addition but a major organizational challenge, which can stem for instance from resistance from leadership and staff, insufficient skills and training, or unclear or complicated regulations (El-Sakka et al., 2025; Eyerman et al., 2013)..

Austria offers a particularly instructive case for examining these dynamics. Nearly half of the population aged 15 and over engages in some form of volunteering, and around one fifth of volunteers do so within civil-protection and rescue organizations (BMSGPK, 2023). Core emergency functions such as firefighting, technical rescue, mountain and water rescue, and large parts of ambulance services are provided predominantly by volunteer-based organizations operating under public authority. The Austrian Red Cross, for example, relies on close to 80,000 volunteers alongside around 10,000 professionals, while mountain and water rescue services are almost entirely volunteer-run (ÖBRD, 2026; ÖRK, 2025). Fire brigades are a paradigmatic example: Apart from a small number of professional brigades in the bigger cities and industrial brigades, most Austrian fire services are fully voluntary, yet they shoulder core responsibilities for firefighting and crisis and disaster response at the local level (Feuerwehr.at, 2019).

Against this backdrop, drones have been introduced as a novel resource into an already complex, multi-level civil protection system. At the federal level, the Ministry of the Interior defines the legal framework and coordinates national civil protection policy, while regional and local authorities hold operational responsibility. Volunteer-based emergency organizations deliver the actual on-the-ground response within this framework. Within the fire services, several federal states have begun to institutionalize drone capacities through dedicated project groups and regional drone bases. In Tyrol, for instance, a state-level drone project group at the state fire brigade federation coordinates UAV use, with multiple drone bases ensuring territorial coverage (LFV-Tirol, 2022). Salzburg, on the other hand, recently introduced a state-wide drone-base system that assigns at least one fire brigade drone unit to every district, with training and operational routines still being expanded (LFV Salzburg, n.d.).

Existing research on drones in crisis and disaster management has primarily emphasized technical capabilities and application scenarios, while the organizational context is often treated as a homogeneous background (Glantz et al., 2020; Mohd Daud et al., 2022; Yucesoy et al., 2025). Where organizational and human factors are addressed, they are typically framed as "barriers" or "enablers" of adoption – such as training needs, funding, and regulatory hurdles – rather than as constitutive elements of how drone technologies are shaped, interpreted, and embedded in practice (Edwards et al., 2024; El-Sakka et al., 2025). Moreover, relatively little is known about how volunteer-based organizations, which depend on unpaid personnel and their availabilities, limited budgets, and strong community ties, develop and institutionalize drone usage compared to professionalized services (Weidinger et al., 2024). This gap is particularly salient in systems like Austria's, where volunteers are not just an auxiliary resource but the backbone of operational crisis and disaster management (Brad et al., 2024).

This paper addresses these gaps by examining drone deployment in Austrian fire brigades through a sociotechnical systems (STS) lens, with a specific focus on differences between professional and volunteer structures. The study treats adoption and operationalization primarily across three dimensions: training and competences, including wearing multiple hats during operations; availability of resources; and decision-making processes about the deployment of the UAV. STS approaches view technologies not as neutral tools but as elements embedded in social relations, organizational structures, institutional norms, and material infrastructures (Bijker et al., 1987; Trist, 1981). From this perspective, decisions about whether, when, and how drones are used in emergencies are sociotechnical processes shaped by formal hierarchies, training regimes, regulatory interpretations, experiential knowledge, organizational attitudes, and resource environments as much as by technical performance. Differences between professional and volunteer fire brigades can, thus, be understood as differences in sociotechnical configurations, such as authority structures, standardization of procedures and institutionalization, interpersonal relations, attitudes towards technology, and forms of commitment and expertise.

Guided by this perspective, the study investigates three questions: (1) How do decision-making processes for drone deployment differ between professional and volunteer disaster-response organizations? (2) What organizational barriers and enabling factors influence the adoption and continuous use of drone technology in volunteer-based and professional fire services? (3) In what ways do resource differences (budget, equipment, personnel) affect drone implementation and operational routines? The research is designed as a qualitative, interview-based, multi-case study focusing on Austrian fire brigades across different federal states. As a work-in-progress contribution to the ISCRAM track "Volunteers in Crisis and Emergency Management", the paper presents the conceptual framework, the empirical context, and the research design, and outlines expected analytical directions for understanding how volunteer-based organizations appropriate and operationalize drone technologies within broader civil-protection systems.

LITERATURE REVIEW

This study is grounded in an STS perspective to analyze the use of drone technology in disaster management organizations. Applying an STS lens allows this study to understand drone procurement and deployment decisions as sociotechnical processes rather than purely technical or managerial choices and to highlight how different organizational settings stabilize distinct "assemblages" of tools, roles, rules, and routines.

Research on drones in crisis and disaster management has grown rapidly and shows a wide range of possible applications. Reviews and scoping studies highlight the potential of UAVs as the "eye in the sky" for situational awareness, damage and needs assessment, and search-and-rescue, but also as communication and logistical support across all phases of the disaster cycle (Glantz et al., 2020; Schmidt & Wrzosek, 2024). Much of this work is strongly technology-centered, detailing sensor payloads, autonomy levels, and routing or optimization algorithms that may increase response speed and efficiency (Li et al., 2024; Romano Correia et al., 2020). Clinical and emergency-medicine perspectives similarly emphasize gains in rapid access, for example through drone-based delivery of medical supplies and automated external defibrillators, or through improved communication links in remote search-and-rescue settings (Johnson et al., 2021; Law et al., 2023; Wankmüller et al., 2021). These contributions demonstrate that drones can, under suitable conditions, reduce response times, strengthen prevention and preparedness strategies and extend the reach of emergency services, but they largely treat organizational contexts as a background condition rather than as an object of analysis in their own right.

A second body of work emphasizes organizational and human factors in drone deployment and focuses mainly on technology acceptance models and ethical concerns of stakeholders (Holzmann et al., 2021; Jeyabalan et al., 2020; Shapira & Cauchard, 2022). Recent human-drone interaction studies explore how autonomous or semi-autonomous systems affect communication, situational awareness, and coordination patterns within firefighting teams, often under experimental or pilot conditions (Li et al., 2024). While these studies begin to address the organizational embedding of drones, they tend to frame organizational structures and resources as external constraints on technology use rather than as constitutive elements of sociotechnical configurations.

From an STS perspective, however, sociomateriality and practices are integral parts of the sociotechnical system. Studies on how different types of organizations – particularly professional versus volunteer disaster management organizations – implement and deploy drones remain scarce. This study addresses these gaps by explicitly comparing professional and volunteer disaster management organizations through an STS lens. It conceptualizes drone operations as sociotechnical configurations that link technological systems, regulatory frameworks, organizational hierarchies and cultures, and embodied expertise. The first research question examines how decision-making processes for drone deployment differ between professional and volunteer organizations, treating decisions as emergent properties of sociotechnical control structures rather than individual choices. The second question investigates organizational barriers and enabling factors - such as training, procurement procedures, legal interpretations, and professional cultures - that influence the adoption and continuous use of drone technology. The third question explores how variations in resources (budget, equipment, personnel, knowledge) give rise to distinct sociotechnical configurations and operational routines. In doing so, the study contributes to sociotechnical analyses of digital innovation in crisis management by showing how organizational sociomaterial contexts shape the ways drones are implemented and used in practice.

METHODS

This study employs a qualitative, comparative case-study design to examine how professional and volunteer disaster management organizations – in this case, Austrian fire brigades as an illustrative example – adopt and implement drone technology. A qualitative approach is well suited for capturing the organizational processes, decision-making dynamics, situated practices, and embodied expertise through which drone technologies become embedded in operational routines. Data is collected through three primary methods: semi-structured interviews, focus group discussions and participant observation. These complementary methods allow for an in-depth understanding of both expressed perspectives and observed practices within operational contexts.

Sampling and Case Selection

The study focuses on fire brigades in Austria, a context in which their work in disaster management is carried out predominantly by volunteers. With the exception of six professional fire brigades and a number of plant and industrial brigades, the vast majority of Austrian fire brigades operate entirely on a voluntary basis. This organizational landscape offers a unique opportunity to examine differences in drone adoption and implementation within a system where volunteerism is the norm but where professional structures also exist.

Austria’s federal governance structure further contributes to the relevance of this case selection. Disaster management falls within the jurisdiction of the individual federal states (Bundesländer), resulting in variations in organizational structures, regulatory frameworks, and operational procedures across regions. These differences provide an environment for comparison and serve as valuable connection points for understanding how organizational and governance configurations may differ in other countries.

Using purposive sampling, the study selects fire brigades that reflect this organizational diversity, including both professional and volunteer units across multiple federal states. Selection criteria include the brigade’s level of experience with drone technology, availability of drone equipment, and involvement in drone-supported operations or training. Within each brigade, participants are recruited based on their direct involvement in drone activities, such as drone operators, team leaders, equipment officers, and command-level personnel. This sampling strategy ensures the inclusion of a diverse set of cases directly addressing the study‘s research questions.

RESULTS

The findings presented here are preliminary, based on the interviews and focus groups conducted to date. Additional interviews are scheduled, and some transcripts remain under analysis. As such, the following results provide early insights into emerging patterns within Austrian fire brigades. They illustrate key sociotechnical dimensions of drone use but not yet capturing the full diversity of organizational experiences.

Overall, the results reveal distinct sociotechnical configurations between volunteer and professional fire brigades. While they operate under the same legal framework, their decision-making, organizational practices, and resource environments differ substantially depending on personnel structure and training, regional system structure, and organizational cultures.

Drone Deployment – RQ1

System structures and models of deployment

Across most federal states, drone operations in fire brigades follow a base station (*Stützpunkt*) model. Depending on the state, two to three drone bases cover the territory, or one base is located in each fire service district. These systems are generally coordinated by the respective state fire service federations and were deliberately kept small during their initial rollout to ensure uniform standards in equipment, training, and operational quality. Concentrating early expertise in a limited number of bases was seen as crucial for developing consistent procedures and accumulating sufficient field experience. As interviewees explained, smaller numbers of base stations made it easier "to monitor and evaluate" training quality and ensure "that enough practical experience with drones during incidents can be achieved." Thus, the number of base stations and which fire brigade got selected were determined primarily by geographic coverage and personnel availability.

Some volunteer brigades acquired drones autonomously before the models were formalized on the state levels; these "wild growth" units currently remain outside the coordinated system and were not included in this study thus far because documentation of ownership and contacts is limited, although efforts are ongoing to include them in this research.

Decision-making and alarm systems

Differences in drone deployment arise from the respective triggering mechanisms defined at the state level. Two models exist: *automated alarm activation* and *manual activation by the incident commander*.

In the automated system, the drone team is alerted simultaneously with other resources through incident keywords. One commander explained:

> "That means we are relatively quickly at the incident site. We are no longer requested half an hour later but try to deploy the drones at a very early stage – to get a good overview of the fire situation, to position the aerial ladder, to arrange the vehicles, and so on. That means not only for monitoring the fire after extinguishing it or long-term searches, but already in the acute and planning phase."

Because of frequent co-activations, these teams accumulated substantial experience in a short time. Other brigades at the scene that witnessed drones in action at their own incidents developed increasingly positive attitudes toward UAVs and gained experiential knowledge in the effectiveness of its use.

In the manual system, the incident commander decides whether to call in a drone unit. As one interviewee noted, "You have to rely quite a bit on every incident commander thinking of it in the situation – that maybe it would be a good support in the current operation." Here the timing depends strongly on personal judgment and experience. Drones are often deployed later ("in the second wave"). This approach reduces false alarms and prevents volunteer fatigue from unnecessary activations but limits early-phase tactical use.

Differences between volunteer and professional brigades are mainly regulatory rather than organizational: activation protocols depend on state rules. In urban settings, the restricted airspace around heli-pads and airports further constrain UAV usage.

Barriers and Enabling Factors – RQ2

Regulations and equipment selection

One federal state has chosen a heavier drone model with the need for a "Specific" category certification[1], which

[1] A 'specific' registration is needed for example when: Flying BVLOS; the drone and its payloads are heavier than 25kg; flying higher than 120m above ground level; when dropping material; when operating a drone heavier than 4kg in an urban environment (EASA, 2026)

prevents operations beyond visual line of sight (BVLOS) in urban areas. Interviewees considered this configuration a major obstacle to effective use: the combination of strict regulations and limited exemptions for fire services significantly restricts operational flexibility and thus, subsequent use of UAVs even in situations where a drone would be obviously beneficial. Early adopters also described the Specific certification process as a major administrative burden with very few precedents to follow. The application demands extensive documentation and incurs costs that volunteer brigades must absorb in their limited budgets.

Comparable challenges arise with special permissions for flights in nature reserves, where prior authorization must be obtained. These administrative and financial barriers mainly affect rural volunteer brigades. In urban areas, clearances must be obtained from local air traffic control towers. If unstaffed, authorization comes from the headquarters of the air traffic control agency in Vienna, where "context information for decisions is often missing." Thus, interviewees noted that brigades often "refrain from using the drone in urban areas in such situations because conventional operational tactics provide faster information."

Across both organizational types, legal frameworks for drone use are strictly defined, but interpretations vary. Professional brigades generally apply regulations conservatively, particularly regarding liability and privacy. Volunteer brigades, in contrast, exhibit a more pragmatic and sometimes experimental approach, described by interviewees as applying "unconventional solutions" when confronted with unclear or constraining rules. These practices reflect an organizational culture that values flexibility and situational problem-solving.

Training and competences

All brigades (professional as well as volunteers) complete the same formal training program for UAVs, yet they differ in how many personnel are certified. Many base stations train about twenty members to ensure a minimum of three available operators per incident. This number requires careful balancing, as too few limit availability and too many reduce motivation and hands-on experience: "The fewer operations you have, the less motivation the team often has to keep practicing."

In volunteer brigades, personnel planning must consider fluctuating attendance: "In the volunteer sector, you need more staff. Because compared to a professional fire brigade where you have a duty roster and know who is there, with us it's more like: let's see who turns up." This is highly dependent on the time and day of the incident.

Professional brigades secure operational readiness through structured shifts:

> "We have at least two drone pilots on duty every day. That's our minimum requirement, because it's possible a drone pilot goes out on deployment for another incident in a different role. That's why all our command vehicle drivers also have drone training and are licensed pilots. This way we can ensure two pilots are always available immediately."

States operating Specific-category drones face capacity bottlenecks at training schools. Limited places in specialized courses restrict how many operators can be certified.

Knowledge creation and dissemination

Knowledge dissemination within volunteer networks emerged as another enabling factor. In regions where incident commanders manually trigger drone teams, regular training and information sessions proved decisive: "Suddenly the number of missions began to rise again – because the idea of using drones was fresh in people's minds, and commanders could imagine what it looked like." Such initiatives help sustain collective learning and maintain organizational competence.

Organizational culture and acceptance

The fire service was repeatedly described as conservative, with initial skepticism toward drones and new technologies in general:

> "Because it was something new, and we still partly have it in the back of our minds – it's my fire, I don't need anyone from outside who might recorded everything, maybe even every mistake I make as incident commander; am I being watched?"

Training and shared exercises were seen as decisive for overcoming these reservations:

> "When we were called to an operation, they already knew the contact persons – the faces, which was very important. And the relevant trust was there. Then the deployment itself showed that the usefulness was convincing enough that people said: hey, that's a great thing, it works."

Acceptance is therefore not only a question of technology but of interpersonal relationships and trust – especially in volunteer brigades, where leadership decisions depend on local familiarity. Professional brigades, in contrast, reported fewer issues with acceptance since the necessary knowledge is available internally.

Resource Environments and Drone Deployment – RQ3

Interestingly, the main dimensions when thinking about resources (budget, personnel, equipment) do not differ immensely between volunteer and professional fire brigades. Budgetary questions were rarely discussed within the sample of this study, and equipment decisions largely follow state standards. Personnel, detailed above, remains the key resource variable – volunteer brigades must balance training enough members to guarantee operational teams while maintaining sufficient opportunities for real-incident experience and thus, keeping motivation for training and continuous exercises high.

The most distinctive resource observed in the interviews though lies in interpersonal relations. One interviewee emphasized that "knowing faces" and understanding "who is responsible for what" are vital forms of knowledge during incidents. Relational trust and team cohesion are seen as essential resources in themselves, supporting effective coordination in complex crisis and disaster settings. Regular joint exercises – not only within one's own brigade but also other fire brigades and across organizations in the wider disaster-management system – strengthen these ties and were identified as a valuable resource that should not be underestimated. Resource differences thus center less on financial capacities than on social and relational infrastructures underpinning competence and collaboration.

Taken together, these preliminary findings illustrate how the integration of drones into Austrian fire brigades is shaped by intersecting social and technical dimensions – organizational hierarchies and decision-making modes, regulatory frameworks, training regimes, and interpersonal networks. While drone use is often framed as a question of equipment and regulation, the cases show that its actual embedding in practice unfolds through sociotechnical processes of coordination, interpretation, and trust. The following discussion situates these emerging patterns within the broader STS perspective adopted in this study.

DISCUSSION

Decision-Making and Control Structures – RQ1

Differences between automated and command-based activation systems reveal contrasting control structures within fire service operations. In the automated model, decision-making is delegated to predefined alarm protocols, producing highly standardized, rapid drone deployment. In contrast, manual activation keeps the decision about drone deployment within the situated judgment of the commander, thus highlighting their situational awareness and embodied knowledge. privileging experiential discretion and local interpretation. From an STS perspective, these configurations represent two sociotechnical modes of control: one centered on procedural automation and infrastructural coordination, and another on embodied knowledge and sense-making under uncertainty. Rather than one system being "better," both exemplify co-production between regulatory systems, organizational hierarchies, and technological capabilities (Naikar, 2018).

Barriers and Enabling Factors – RQ2

The second set of findings confirms that barriers to drone implementation arise from institutional coupling between regulation, equipment choice, and organizational capacity. Strict certification processes (such as Specific category registration) reflect broader governance logics prioritizing safety and procedural accountability. In urban professional settings, however, these administrative demands collide with imaginations of effective drone use, highlighting how bureaucratic processes and its perceived usefulness in practice shape technological usage. Conversely, enabling factors – especially shared training sessions and interpersonal trust – demonstrate that social relations can act as infrastructural resources. The interviews show how relational trust and inter-organizational familiarity compensate for structural asymmetries, creating informal channels of coordination where formal procedures remain rigid. This underscores a core STS insight: technology adoption depends not only on compliance with rules but on the social infrastructures that make those rules workable in practice (Bijker et al., 1987; Krogh & Lo, 2023).

Resource Environments – RQ3

The third research question revealed that resource disparities are not primarily financial but relational and organizational. Across both brigade types, funding and equipment levels were similar; the decisive resource was continuity in personnel and interpersonal familiarity within drone teams. "Knowing faces," as one respondent phrased it, emerged as a crucial form of situated knowing that stabilizes collective action under volunteer conditions. These findings invite rethinking "resources" beyond material categories: human relations, shared training histories, and mutual recognition constitute the social capital through which drone operations become reliable and legitimate. Regular joint exercises act as boundary-objects connecting distributed stakeholders – fire brigades, regional authorities, and other rescue services – thus reinforcing networked resilience within Austria's civil protection landscape (Kalkman, 2020; Wardropper et al., 2025).

CONCLUSION

This paper has shown that the adoption and operationalization of drones in Austrian fire brigades cannot be understood as a simple question of technological efficiency or equipment acquisition. Rather, drone use emerges through sociotechnical configurations in which decision-making structures, regulatory frameworks, training arrangements, and interpersonal relations interact to shape whether and how UAVs become part of crisis and disaster management practice. From this perspective, the contrast between professional and volunteer brigades is not merely a matter of staffing or formal organization, but of different ways of coordinating expertise, authority, and operational readiness.

The findings indicate that deployment models matter significantly. Automated alarm systems promote rapid and standardized drone activation, while manual systems depend more heavily on the judgment of individual commanders. Both approaches have advantages and limitations, but they reveal different forms of sociotechnical control. In addition, regulatory requirements, certification procedures, and airspace restrictions often act as major constraints, especially where they intersect with limited personnel and administrative capacity. At the same time, training, repeated exercises, and personal familiarity across organizations can function as enabling conditions that stabilize drone use and increase acceptance.

A central contribution of the study is its rethinking of "resources." The results suggest that drone implementation depends not only on budgets, equipment, or formal staffing levels, but also on relational and cultural resources such as trust, mutual recognition, and shared experience. This is especially important in volunteer-based fire brigades, where operational availability varies and knowledge must be continuously reproduced through collective practice. In this sense, volunteerism should not be treated as a secondary feature of crisis and disaster management, but as a defining sociotechnical condition that shapes technology adoption and use.

Outlook

This paper only offers preliminary analysis of the collected material as data collection is ongoing .Once empirical analysis is completed, the study will be able to offer practice-oriented implications for the design of drone programs that make effective use of volunteer engagement while addressing issues of training, workload, and long-term sustainability. These implications are relevant not only for Austria but also for other countries where volunteerism forms a key pillar of emergency response. More broadly, the paper seeks to contribute to ISCRAM debates the integration of novel technologies in crisis and disaster management systems that rely to a large amount on volunteers, illustrating how an STS perspective can enrich discussions of interoperability, governance, and resilience.

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