JOURNAL OF MODERN SCIENCE
2/66/2026
www.jomswsge.com
DOI: 10.13166/jms/224794

MAŁGORZATA SUCHACKA
University of Silesia in Katowice, Poland
ORCID iD: 0000-0002-3769-5892

ZUZANNA NEUVE-EGLISE
University of Silesia in Katowice, Poland
ORCID iD: 0000-0002-4062-0947

MIROSŁAW SKOREK
University of Silesia in Katowice, Poland
ORCID iD: 0009-0001-5873-1936

THE ROLE OF NEW TECHNOLOGIES IN THE CONTEXT OF SECURITY IN SELECTED AREAS OF THE SMART CITY - THE CASE OF POLISH FIRE SERVICE

Abstract

Objectives: *This article aims to analyse documents and case studies of fire brigade activities in the context of smart city functioning.*

Methods: *For the purpose of this study, the authors adopted a qualitative research approach that included document analysis and analysis of exceptional cases meeting the criterion of technology use during operational activities.*

Results: *The study has shown that the digitalisation process in the State Fire Service (PSP) represents not only technological modernisation but also a complex social phenomenon inherent in the logic of smart city development. The analysis of institutional documents and practices has revealed that digital tools are changing operational procedures, redefining relationships between services and communities, becoming a means of building trust and institutional legitimacy. Simultaneously, an 'implementation gap' has been revealed – a discrepancy between normative assumptions and the daily practice of rescue operations – indicating the need for flexible adaptation.*

Conclusions*: The effectiveness of innovative solutions depends not only on the systems themselves but also on adaptability, collaboration, and the joint development of safety standards. The smart city thus emerges as a dynamic socio-technical system in which security arises from a constant negotiation between the promise of technological control and the real experience of risk and uncertainty.*

Keywords: *smart city, fire brigade, new technologies, security, crisis management*

Streszczenie

Cel: *Celem artykułu jest analiza dokumentów i studiów przypadku dotyczących działalności straży pożarnej w kontekście funkcjonowania miasta inteligentnego.*

Metody: *Dla potrzeb tego opracowania autorzy zdecydowali się na metodę jakościową uwzględniającą analizę treści dokumentów oraz analizę wyjątkowych przypadków spełniających kryterium zastosowania technologii podczas działań operacyjnych.*

Wyniki: *Badania wykazały, że proces cyfryzacji w Państwowej Straży Pożarnej (PSP) stanowi nie tylko modernizację technologiczną, ale także złożone zjawisko społeczne wpisane w logikę rozwoju smart city. Analiza dokumentów i praktyk instytucjonalnych pokazała, że cyfrowe narzędzia zmieniają procedury operacyjne, redefiniują relacje między służbami a społecznościami oraz stają się medium budowania zaufania i legitymizacji instytucjonalnej. Ujawniono jednocześnie istnienie luki implementacyjnej – rozbieżności między założeniami normatywnymi a codzienną praktyką działań ratowniczych – wskazującej na konieczność elastycznej adaptacji.*

Wnioski: *Skuteczność innowacyjnych rozwiązań zależy nie tylko od samych systemów, lecz także od zdolności adaptacyjnych, współpracy oraz wspólnego kształtowania standardów bezpieczeństwa. Smart city jawi się zatem jako dynamiczny układ społeczno-techniczny, w którym bezpieczeństwo powstaje w wyniku ciągłej negocjacji między obietnicą technologicznej kontroli a realnym doświadczeniem ryzyka i niepewności.*

Słowa kluczowe: *smart city, straż pożarna, nowe technologie, bezpieczeństwo, zarządzanie kryzysowe*

Introduction: the purpose of analysis

The dynamic development of the smart city concept presents researchers and public security practitioners with new challenges, while also opening a broad field for discussion on the role of technology in crisis management processes. A smart city is not merely an urban space enriched with digital infrastructure; it is also a socio-technical system in which the safety of residents becomes one of the key dimensions through which local authorities and public institutions derive their legitimacy. In cities that are actively implementing digital solutions – from smart energy grids and environmental sensors to integrated management centres – security remains a fundamental category that conditions stability, development, and the everyday comfort of residents.

In particular, within the context of fire safety, flood prevention, and broader crisis management, the fire service emerges as an institution of special importance. In contemporary smart city environments, its activities increasingly encompass risk monitoring, coordination of operations among different emergency services, and participation in spatial planning and critical infrastructure management. The fire service thus becomes an actor that must operate simultaneously in both physical and digital spaces, making use of geographic information systems (GIS), Internet of Things (IoT) sensor networks, big data analytics, and real-time communication platforms.

This article aims to analyse the policy and regulatory documents that structure and define the activities of the Polish fire service in relation to security within smart cities. This analysis allows for the identification of the formal and organisational frameworks within which the service operates, as well as an

assessment of the extent to which existing regulations and strategies account for the specificities of new technologies. At the same time, the article includes a problem-oriented analysis based on selected rescue operations, illustrating practical challenges linked to the use of technological tools. These case studies highlight both the positive aspects of implementing modern solutions (e.g. faster incident localisation, more precise forecasting) and the limitations associated with technological dependencies (e.g. system failures, issues of interoperability across platforms).

Without a nuanced understanding of the role of the fire service and the technologies that support emergency response, the smart city concept remains incomplete – reduced to a technocratic rather than a socio-technical vision. In this respect, the analysis of policy documents and case studies concerning the activities of the State Fire Service (Polish: *Państwowa Straż Pożarna*, PSP) constitutes an important step toward a more comprehensive understanding of how safety and security are embedded in the everyday functioning of the smart city.

Dimensions of the Smart City in the Context of Urban and Regional Security: Theoretical Assumptions

The concept of the smart city emerged as a response to the complex challenges faced by contemporary urban areas – rapid urbanisation, infrastructural overload, environmental degradation, and the need to enhance both residents' quality of life and the efficiency of urban management. In this respect, it aligns with other urban development paradigms, such as the innovative city and the sustainable city (Baraniewicz-Kotasińska, 2023, pp. 52–53) through the promotion of shared principles. Elements of sustainable development are deeply embedded in the definition of the smart city adopted by international organisations concerned with urban issues (UN-Habitat, 2023, p. 1). The popularisation of the smart city idea has undoubtedly been driven by IT corporations; however, scholars in this field (Nam & Pardo, 2011) argue that the concept extends beyond infrastructure to include a culture of innovation, social capital, and integrated public governance.

The academic literature offers a range of interpretations of the smart city concept (Baraniewicz-Kotasińska, 2023). In its classical model, six key dimensions are identified: smart economy, smart governance, smart mobility, smart environment, smart people, and smart living (Giffinger et al., 2007). A city is considered smart when it achieves high standards across these domains. Increasingly, however, public safety is being recognised as a crucial component of urban infrastructure and services. In more recent approaches and strategic documents (Ismagilova et al., 2022; *ISO 37122*, 2019; Laufs et al., 2020; UN-Habitat, 2024), safety is treated as a distinct element – referred to as smart security, public safety (Allam & Newman, 2018, p. 10), or safe city (Lacinák & Ristvej, 2017, p. 523). This includes crime and terrorism prevention, cybersecurity, effective emergency response, and the enhancement of urban resilience to threats (Wereda et al., 2025). Such a trend is unsurprising, given that broadly understood safety constitutes the foundation of urban life and directly corresponds to Goal 11 of the United Nations 2030 Agenda for Sustainable Development – Sustainable Cities and Communities: 'make cities and human settlements inclusive, safe, resilient and sustainable' (United Nations, 2015). This demonstrates that safety is not merely a by-product of smart city technologies but a fundamental priority of contemporary urban policy worldwide.

Consequently, security issues are increasingly reflected in the technologies implemented within smart city frameworks, which rely on advanced digital solutions (Baryłka, 2015). Within the key components of the smart city, attention is given to the integration of technologies such as the IoT, big data analytics, artificial intelligence (AI), GIS, and cloud infrastructures for monitoring and managing transport, energy, waste, and public safety (Batty et al., 2012; Hashem et al., 2016). Across the globe, emergency services – police, fire brigades, and ambulance units – are testing and adopting advanced technologies for preventive measures, faster response to both physical and digital threats, improved coordination, and more efficient resource management. Among the most relevant tools and solutions are the following:

a. Intelligent emergency management systems – they integrate data from various sources (IoT sensors, surveillance systems, citizen reports, meteorological data), and enable real-time analysis (Adreani et al., 2024; Damaševičius et al., 2023; Pirklbauer & Findling, 2021).

b. IoT-based threat detection – IoT sensors embedded across urban spaces (e.g. in buildings, streetlights, roads) can detect fires, seismic activity, gas leaks, and floods. Once a threat is identified, the system automatically alerts the relevant services and transmits location and contextual data (Mohsin & Muyeed, 2024; Zhang et al., 2025), significantly reducing response time and improving intervention precision.
c. Location and navigation systems – using GPS, GIS, and 5G networks, emergency responders can be dynamically directed to incidents along optimal routes, taking into account current traffic conditions (Lee & Chiu, 2020). Predictive systems, drawing on historical data and AI, can also indicate high-risk zones (Costa et al., 2022).
d. Communication platforms and interoperability – they enable data sharing among police, fire services, medical responders, and administrative bodies (Wolf et al., 2022), thus facilitating coordination and preventing duplication of resources.
e. Drones and rescue robotics – unmanned aerial vehicles are increasingly deployed for rapid reconnaissance, equipment delivery, or locating missing persons – particularly in difficult-to-access areas (Erdelj et al., 2017; Lyu et al., 2023) – as well as for monitoring environmental threats (Parczewski, 2024; Surmann et al., 2022).

The literature indicates that smart city technologies provide a wide array of tools for enhancing public safety – from surveillance systems (Gonçalves et al., 2021; Johnson et al., 2024) to integrated crisis management (Lee & Kukita 2018; Pettet et al., 2021; Zhang et al., 2025). Yet across different smart city components, including safety and emergency response, there is a growing need for a more balanced approach to technology adoption – one that considers ethical, social, and legal dimensions. The implementation of new technologies generates novel forms of technological, organisational, and social risks which, following Ulrich Beck's theory (Beck, 2002), require critical reflection. The introduction of technological systems into social practice thus demands transparency, public oversight, and ethically informed design (Kitchin, 2016).

Modern risks play both symbolic and mobilising roles, often triggering strong public reactions, such as fear, institutional distrust, or scepticism towards

science. Risk management, therefore, is not merely a technical concern but also a social and political issue intertwined with public trust in technology. In the context of smart cities, such trust forms the foundation of societal acceptance for systems of surveillance, automation, and data analytics. The notion of 'digital trust' remains a crucial yet still underdeveloped element of the digital economy (Pietrzak & Takala, 2021). Trust in technical systems is built upon confidence in their reliability and in the integrity of the institutions deploying them (Ejdys, 2017, pp. 25–26), as well as on communicative openness and the quality of implementation processes (Fountain, 2001). In the field of crisis management, the effectiveness of emergency services thus depends not only on their operational capacity but also on public confidence that they act transparently, competently, and in the public interest. Advanced technologies supporting emergency response hold significant potential to enhance the speed, precision, and effectiveness of interventions. Nonetheless, important research gaps persist regarding their application within the fire service – particularly the limited attention to non-fire activities (e.g. technical and chemical rescue), support for planning and operational decision-making, interoperability between technological systems, and the understanding of firefighters' needs, organisational constraints, and attitudes towards technology (Weidinger, 2022).

Research methods

For the purposes of this study, the authors adopted a qualitative research approach incorporating both document analysis and case study analysis, which together enable an in-depth examination of the nuances involved in the application of technology during operational activities.

The documents selected for content analysis were chosen purposively and in a problem-oriented manner, in accordance with the criterion-based selection principle commonly applied in qualitative research (Glinka et al., 2021). This analysis aims to examine both the intended and the actual use of information and communication technologies (ICT) in the operations of the State Fire Service, as well as to outline their role in building the resilience of urban security systems within the framework of the smart city concept. The analysed materials comprise both normative (legal acts, instructions,

plans) and empirical sources (academic studies, doctoral dissertations, case reports), enabling the exploration of diverse perspectives – organisational, technological, and social. The analysis included documents meeting the following criteria:

- direct relevance to PSP activities, with particular attention to command structures, decision-making processes, and crisis management,
- reference to issues of digitalisation, automation, data processing, and the use of IT tools in operational and preventive activities;
- illustration of organisational, competency-related, and procedural changes resulting from the implementation of digital technologies;
- social aspects – references to the organisational culture of emergency services, the adaptation of technology by personnel, and the impact of new tools on interactions between the fire service and the urban community.

Such a selection enables triangulation of content, bringing together regulations, theoretical frameworks, and operational experiences. Given the diversity of materials, the content analysis focuses primarily on their objectives, scope, and the key issues they address. An additional selection criterion was the practical relevance of the documents to operational activities.

An equally important part of the research, complementing the document analysis, involves case studies illustrating the implementation of IT technologies in crisis situations (e.g. floods, fires, traffic disasters). Reflections are organised around several analytical areas. These include, first and foremost, the effectiveness of technological solutions in real-life emergency contexts, as well as the cooperation of rescue services not only at the local level but also regionally and internationally. Other key aspects concern the role of data and artificial intelligence in threat prediction, and the preparation of fire service teams through education and training programmes. Particular attention is also given to challenges related to institutional responsibility for technology-supported decision-making and to the fair, inclusive use of technology – avoiding the exclusion of certain social groups (e.g. older adults or those with lower levels of education).

This combination of documentary and empirical material grounds the analysis within both the paradigms of the sociology of institutions and organisations, and security studies – with a focus on examining the effectiveness of structures

and processes under conditions of risk and uncertainty. The integration of these two research techniques enables a deeper understanding of how the state and its institutions articulate expectations towards emergency services regarding digitalisation, command, and crisis management, and whether these expectations are coherent, adequate, and responsive to contemporary threats. This, in turn, enables a critical assessment of the 'implementation gap' – the divergence between assumptions and practice. Such a context provides a foundation for evaluating the extent to which local initiatives align with global trends in the implementation of smart rescue and emergency informatics solutions.

Document Analysis: Purpose, Scope, Key Issues, and Practical Relevance

A total of ten documents of both official and analytical-academic character were included in the analysis. The examination of these selected materials – pertaining to the functioning of the PSP and works related to security systems – reveals a number of recurring themes that make it possible to capture the dynamics of the transformation of emergency services towards more integrated, digital, and flexible structures, characteristic of the smart city concept.

Table 1. *Document analysis: overview of objectives and scope*

	Document Title	Purpose and scope
1.	**A Mobile Application to Support Decision-Making in the Context of Forest Fires**	Description of a mobile application for Brazilian firefighters combating wildfires
2.	**GIS Technology and Applications for the Fire Service (2006)**	Use of GIS systems in the fire service across all aspects of its operations
3.	**Firefighting in the New Economy: Changes in skill and the impact of technology (2010)**	Doctoral dissertation by Brian W. Ward concerning changes in firefighters' skills under the influence of technology
4.	**Host Nation Support (HNS) Task Allocation Plan in PSP (May 2019)**	HNS principles for the State Fire Service (PSP) in the presence of allied military forces
5.	**Regulation on the Detailed Organisation of the National Firefighting and Rescue System (KSRG, 2021)**	Legal foundations of the functioning of the National Firefighting and Rescue System (Polish: *Krajowy system ratowniczo-gaśniczy*, KSRG) – defining detailed principles governing the system's operation, including firefighting, technical, chemical, and medical rescue, as well as the rules for force deployment, operational command, and documentation management
6.	**ICT Support for the Incident Commander (2024)**	Doctoral dissertation by Łukasz Olejnik concerning the diagnosis of problems in the decision-making process by the Incident Commander and a proposed IT application for the Incident Commander
7.	**Principles for the Recording of Incidents in the State Fire Service Command Support System (SWD PSP) (2023)**	Instruction defining the principles for recording and describing all incidents in the State Fire Service Command Support System (SWD PSP)
8.	**Principles for the Organisation of Command Posts for Conducting Rescue Operations (January 2025)**	Standardisation of the functioning of command posts – the latest version of the official PSP guidelines concerning the organisation and operation of command posts during rescue operations
9.	**Principles for the Organisation of Rescue Operations (2013)**	Supplementation and elaboration of the KSRG regulation provisions – systematisation of issues related to the proper execution of tasks by Incident Commanders at all levels of command
10.	**Ministry of the Interior and Administration (MSWiA) Programme 'Resilience to Crisis: Optimisation of State Services Responsible for Security'**	Modernisation of public alert systems financed through the National Recovery Plan (KPO)

The document analysis has revealed that their primary purpose is to outline both the formal and the technological frameworks that govern the operations of contemporary PSP structures in the context of the smart city concept and the growing role of IT in civil protection. The scope of the materials includes both legal acts and organisational guidelines (regulating the structure of the National Firefighting and Rescue System (Polish: *Krajowy system ratowniczo-gaśniczy*, KSRG), command staff, and record-keeping procedures), as well as research analyses, expert reports, and examples of technological solutions (mobile applications, GIS systems, communication and alarm tools). The key issues emerging across the analysed materials can be organised into three main dimensions.

The central recurring theme is the ongoing digitalisation of command, communication, and record-keeping processes. Guidelines concerning staff organisation, event registration in the PSP Command Support System (SWD) system, and studies on ICT support for incident commanders emphasise the need to create an environment in which operational data – from rescue plans to drone imagery – are available in real time, integrated, and capable of automated processing. Such solutions enhance not only operational efficiency but also transparency, which in the broader perspective fosters public trust in emergency services. From a sociological standpoint, this reflects growing 'institutional openness,' where technology not only supports internal operations but also becomes a tool for communication with citizens and external partners.

A second important theme is the integration of advanced technological tools into the very tactics and logistics of emergency operations. Drones, GIS systems, satellite communications, and model-based forecasts – all referenced in documents concerning staff organisation, host nation support plans, and technology white papers – expand capabilities for reconnaissance, monitoring, and operational planning. Within the smart city framework, these technologies are not merely operational support; they also empower residents to participate in creating urban safety – both through access to rapid warning systems (such as the modernised population alert system based on digitally controlled sirens and integration with RSO or RCB apps[1] used in Poland) and through greater transparency and predictability in emergency service activities.

The third shared dimension concerns changes in competencies and relational dynamics within emergency services. Documents – particularly

scholarly works on the impact of technology on firefighter skills – highlight the necessity of continuous professional development, acquisition of new digital competencies, and adaptation to evolving work conditions. The requirement to operate modern information systems, handle ICT equipment, and analyse data not only alters task structures but also redefines internal and external relationships. Firefighters become operators of complex information systems, while citizens may perceive their actions as more professional, transparent, and knowledge-based. This, in turn, supports the building of social trust and the perception that security institutions are capable of meeting modern challenges.

The analysed documents – their purposes, scope, key areas, and practical relevance – provide a solid foundation for examining how smart technologies translate into the real-world behaviour of emergency services during crises. Case study analysis – for example, interventions during floods or gas explosions – enables an assessment not only of the effectiveness of the deployed solutions but also of their impact on social trust, the sense of safety, and relationships within local support networks.

Case Study Analysis: Problem-Oriented Approach

The case study analysis covered several events that occurred in Poland during the past year and at the turn of 2024 and 2025. These included, among others, the gas explosion in Cieszyn on 29 December 2024 (*Pożar i zawalenie się kamienicy w Cieszynie*, 2025), the floods in Lądek-Zdrój and Stronie Śląskie in September 2024 (*Strażacy w działaniach przeciwpowodziowych*, 2024), weather anomalies in the Podkarpackie Province in 2025 (Łańcut News, 2025), and the functionality of the Intelligent Transportation System (ITS) in Tychy since mid-2022 (ITS Tychy, 2022). The analysis primarily focused on the effectiveness of implemented solutions, their impact on regional and international cooperation in crisis management, the role of education and training, and ethical and social responsibility considerations in the context of modern technologies.

Effectiveness of implemented technological solutions in real-world crisis situations

The analysis of the effectiveness of technological solutions in real-world crisis situations provides a comprehensive understanding of their practical application and highlights areas for further development or adaptation. The rescue operation following the collapse of a tenement building in Cieszyn on 29 December 2024 serves as a case study of the use of specialised technologies in a structural disaster. In search-and-rescue operations conducted by the Specialist Search and Rescue Group, rescue dogs played a key role, supplemented by thermal imaging cameras to locate victims beneath the rubble. Command processes were supported by computer software, enabling real-time tracking of forces and resources, which enhanced decision-making efficiency and ensured accurate communication with the public.

Crisis management also demonstrates adaptive use of digital resources originally developed for other purposes. Digital architectural and construction documentation, created for inventory or investment processes, as well as geospatial data, can be integrated into command systems. GISs allow for the aggregation of dispersed data into a large-scale, unified operational picture, significantly enhancing situational awareness. In disasters such as gas explosions and building collapses, the effectiveness of technological solutions is measured by the speed and precision of response.

During the Cieszyn operation, the synergy between command support software (SWD, Staff Support Systems – SWS) and digital communication platforms was crucial. By aggregating real-time data, the software created a common operational picture, enabling digital tracking, resource balancing, and visualisation, thereby supporting proactive, data-driven decision-making. The platform facilitated optimal allocation of forces and resources and served as the basis for interoperability, integrating the activities of multiple services within a single coherent system.

However, the deployment of advanced technologies in structural disaster scenarios faces fundamental operational limitations. The effectiveness of sensors, such as thermal cameras, is reduced by environmental conditions (e.g. dust), and equipment remains vulnerable to mechanical damage.

Key challenges also include ensuring power supply and interoperability between systems, which can hinder the creation of a common operational picture. Monitoring structural stability – essential for safety – imposes strict procedures, including standardised evacuation signals and operational silence for seismic-acoustic devices (geophones). Despite these technical constraints, human factors remain paramount. The ultimate success and safety of operations depend directly on the psychophysical condition, adaptability, and tactical discipline of rescue teams.

Analysis of rescue operations during the floods in Lądek-Zdrój and the storms in the Łańcut region in Poland demonstrates the conditional effectiveness of IT systems in crisis management. In the case of flooding, cascading infrastructure failures (loss of power, communications, and road access) led to a complete digital and logistical paralysis. Advanced technologies, such as drones for damage mapping and GIS systems, became useful only after basic connectivity was restored using generators and satellite terminals. This case illustrates that digital management systems are fully dependent on physical infrastructure. Furthermore, partial failures of centralised platforms highlighted the primacy of human factors – staff adaptability and competence, rather than technology alone, enabled the deployment of alternative solutions (e.g. cloud-based systems) and continuity of command. During storms in the Łańcut region, characterised by hundreds of dispersed, short-duration events, the dedicated IT system proved ineffective. The time required to input data from each incident outweighed the benefits of digitalisation, making the system a hindrance to reporting.

In must be stressed that the problem was not the nature of the incidents but their scale and territorial spread. This is confirmed by interventions in the Pawłosiów municipality, where similar incidents were successfully managed by the same system. Key factors enabling effective use included a limited operational area (within one municipality) and a relatively stable composition of forces and resources, which simplified record-keeping and reporting. Both cases demonstrate that IT system effectiveness is determined not only by technological sophistication but also by infrastructure stability, incident characteristics, and the synergy between technology and operator knowledge and creativity.

The initiation of PSP rescue operations is directly contingent on the physical arrival of personnel at the incident site (Regulation of the Ministry of Interior and Administration on the Detailed Organisation of the National Firefighting and Rescue System, 2021, §21(1)). Response time is therefore a critical parameter determining overall operational effectiveness. To optimise response times, the city of Tychy implemented an ITS as part of its smart city initiatives. A key feature aimed at reducing PSP vehicle travel time is the 'green wave' priority system. Upon detection of an emergency vehicle with active warning lights, the ITS dynamically adjusts traffic light cycles along the route, providing a green signal for the privileged vehicle while halting cross-traffic, ensuring smooth passage and minimising collision risk. For incidents occurring directly at intersections, the priority can be manually deactivated by the vehicle driver or system administrator, preventing traffic disruption and enabling safe rescue operations.

The impact of ITS on PSP operations extends beyond the green wave. The system is part of a broader smart city infrastructure, providing essential tools for firefighters and dispatchers. A network of surveillance cameras integrated with the system supplies critical information to the Municipal Command Centre. Before the first units arrive, dispatchers can conduct preliminary assessments, gauge threat levels, and identify potential hazards (e.g. hazardous materials). This complements the SWD system, where dispatchers access incident data from the Emergency Notification Centre, including audio recordings of calls, allowing verification of key information, refining location details, and identifying additional risks reported by callers.

Another aspect of technology use is on-site communication and operational management, supported by the Terminal ST system installed on in-vehicle tablets. This enables two-way information exchange between units and the command centre. Firefighters can send notes and photos from the scene, providing the dispatcher with a more complete situational picture. The system also tracks vehicle locations, enabling optimal resource management. For Volunteer Fire Brigades, the system allows rapid reporting of crew composition, essential for assessing rescue capacity on-site.

The implementation of such advanced and comprehensive solutions would not have been possible without active involvement from firefighters. PSP

personnel were engaged from the outset, participating in system testing, training on new equipment and software, and providing feedback critical to initial optimisation. This close collaboration between technologists and end-users ensured the system was not only innovative but also functional, enhancing operational effectiveness and safety.

The analysis of crisis events confirms that technologies such as GIS, satellite data, and drones substantially improve emergency service effectiveness (*Rozwój grup dronowych w PSP*, n.d.) These tools enable precise hazard modelling, real-time situational monitoring – such as dynamic flood mapping via drones – and more efficient coordination of multi-agency operations. Data collected during operations also inform updates to crisis management plans during recovery phases. Despite challenges, including data processing delays and coordination difficulties, these technologies fundamentally enhance the ability of emergency services to respond quickly and mitigate disaster impacts, underscoring their critical role in modern crisis management.

Cooperation of emergency services at local, regional, and international levels

Contemporary crises, such as floods, transcend borders, making effective international cooperation essential for rapid and efficient response. Technologies play a key role in removing communication and organisational barriers. The use of AI and data in risk management allows for improved crisis prediction and optimisation of rescue operations, transforming traditional response methods.

International rescue operations rely on procedural standards, such as the Union Civil Protection Mechanism (UCPM) (*UMPC*, 2023), where success depends more on standardisation and cooperation than on fully integrated technology. Resource tracking is often conducted manually, highlighting interoperability challenges. In this context, information technology functions as a lingua franca, enabling precise communication across language barriers via universal visual layers, such as standardised tactical symbols in GIS systems. Currently, AI in the Polish PSP is in the research and development phase. A predictive-advisory system is being developed to analyse historical data

and generate tactical recommendations. Its operation is based on a human-in-the-loop principle, meaning AI provides advisory support, but the final expert decision always rests with the commanding officer.

The UCPM mechanism facilitates mutual assistance among member and partner states during crises. Participation requires readiness and certified, self-sufficient rescue modules meeting standardised requirements for training, equipment, and full operational autonomy.

The Polish HUSAR heavy search-and-rescue team, operating within the UCPM, exemplifies such a self-sufficient module. During the 2023 earthquake in Turkey (*Polscy strażacy z pomocą ratowniczą dla Turcji dotkniętej trzęsieniem ziemi*, 2023), the HUSAR team operated as an independent technological ecosystem, replacing the destroyed local infrastructure. Advanced sensor networks, including geophones and specialised cameras, were used for locating survivors, while drones assessed damage and supported operational planning. The operation relied on autonomous infrastructure, including satellite communication and generator-based power supply, ensuring full operational independence in the disaster zone.

The effectiveness of the HUSAR team depends on a rigorous training and certification system. Training is continuous and multi-stage, grounded in years of service within one of the national Specialised Search-and-Rescue Groups. Key components include narrow specialisations (e.g. dog handlers, geophone operators, medics) and regular national exercises to integrate the team. The ultimate confirmation of world-class standards is an intensive, international UN recertification (INSARAG), held every five years; the latest took place in Gdańsk, 14–17 April 2025 (*Recertyfikacja HUSAR Poland w Gdańsku*, 2025).

The role of data and AI in predicting hazards, and the preparation of PSP teams through educational and training programmes

The effectiveness of advanced technologies in security systems is inseparable from personnel competence. PSP prioritises skill development before equipment deployment. A notable example is the participatory implementation of the SWS system, where active involvement of personnel in software

development resulted in practical, usable features (Skorek, 2024). This approach was validated when two command centres – county and provincial – operated simultaneously on a single application in real-time during the Cieszyn gas explosion rescue operation. This multi-level training philosophy, confirmed during the disasters of 2024–2025, ensures that personnel actively adapt to new technologies. The synergy between equipment, knowledge, and experience transforms technology into a transparent tool that enhances a rescuer's capability rather than adding cognitive load. Among major PSP challenges is the universal rescuer model, which can limit deep specialist competence. Specialist tasks, such as GIS operation or advanced IT functions, often require near-from-scratch learning, constrained by operational duties. Rapid technological development also makes it difficult to maintain up-to-date knowledge. Even short interruptions in use can lead to a decline in competence. While external expert support is sometimes used, personnel bear primary responsibility for skill maintenance. Superficial familiarity with tools risks errors or delays in critical moments, undermining the benefits of technology deployment.

A systematic response to these challenges is exemplified by the SWS implementation, combined with regular training involving internal trainers and software vendor representatives. This model ensures not only initial training but also continuous refreshment and consolidation of practical skills. Despite the universal nature of the service, this approach allows achievement and maintenance of a necessary proficiency level in key software, directly translating into effective utilisation during rescue operations.

Institutional responsibility for technology-based decisions: ethical considerations

The introduction of advanced technologies in public trust institutions, such as the PSP, raises fundamental ethical, legal, and social challenges that extend beyond purely technical considerations. A central concern is accountability for algorithm-assisted decisions, where responsibility can become diffused among the operator, software developer, and the institution itself, potentially exacerbating the opaque nature of some systems. Another critical issue is the risk of generating new

forms of social exclusion. The digital divide may prevent crucial warnings from reaching groups with lower technological literacy, as evidenced during the 2024 floods in Lądek-Zdrój (*Nigdy nie lekceważ ostrzeżeń*, 2024). Furthermore, learning algorithms trained on historical data may inadvertently reinforce existing biases. Consequently, the responsible implementation of technology within emergency services requires a holistic approach that encompasses the development of new legal frameworks, the implementation of transparent systems, and deliberate efforts to mitigate digital exclusion, ensuring that technological progress contributes to enhancing the safety of society as a whole in a fair and sustainable manner.

Research limitations

Every scientific study, particularly in a complex domain such as urban safety in smart cities, is subject to certain limitations. The authors of this study acknowledge that the adopted methodology – document analysis and selected case studies – does not allow for full representativeness or for capturing the entire diversity of practices. The selection of materials was purposive and criteria-based, targeting specific research questions, which inevitably entails the omission of many other aspects of PSP operations in the context of smart cities. The documents primarily reflect official institutional discourse, while the crisis cases – though analytically rich – are illustrative rather than generalisable.

This deliberate perspective stems from factual limitations in accessing operational data and practices, which, for formal and ethical reasons, remain partially restricted. In this context, documents and case studies allow, on the one hand, for capturing organisational and technological frameworks, and on the other, for revealing mechanisms, tensions, and paradoxes associated with the use of new technologies in rescue operations. The authors emphasise that their intention was not to provide a complete picture of reality but rather to indicate directions for reflection and further research.

The choice of qualitative methods thus represents a compromise between research aspirations and the realities of the field. It is a conscious decision aligned with the tradition of qualitative research, which prioritises in-depth understanding over broad replicability. This study should therefore be treated as a preliminary stage – a first attempt to map the area, which requires further

analyses, including quantitative or participatory approaches. It is an invitation to engage in discussion on how smart city technologies shape urban safety and the social consequences arising from their implementation.

Concluding remarks

The study reveals a number of conclusions that can be interpreted from the perspective of institutional and organisational sociology. Firstly, document analysis indicates the growing role of digitalisation and automation in the functioning of the PSP. From a sociological standpoint, this marks a shift from the classical role of a rescue institution towards an actor embedded within a complex socio-technical system, characteristic of the smart city.

The analysis of the collected materials demonstrates that the process of digitalising security is not merely a technical modernisation of the services, but a complex social phenomenon aligned with the logic of smart city development. The documents, encompassing legal frameworks, scientific research findings, and practical institutional experiences, create a coherent narrative of transformation occurring at multiple levels – from changes in procedures and operational tools to the redefinition of relationships between security institutions and urban communities. Secondly, the analysis indicates that the effectiveness of technological solutions depends not only on the innovativeness of the systems but also on the capacity of institutions and personnel to adapt, collaborate, and jointly shape safety standards. The research thus reveals that a smart city is not a space free of uncertainty but rather a field of negotiation between the promise of control and the actual experience of system fallibility. The analysis of documents and cases has revealed an 'implementation gap' – a discrepancy between normative assumptions and the daily practice of rescue operations. This tension is typical for institutions operating under conditions of risk and uncertainty, where procedures must be flexibly reinterpreted.

In conclusion, the study shows that modern tools can enhance operational effectiveness but simultaneously require trust, competence, and adaptive capacity. In this sense, the smart city emerges as a dynamic socio-technical system in which safety results from the interaction of humans and technology within a world of persistent risk.

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Endnotes

[1] The Regional Warning System (Polish: *Regionalny System Ostrzegania* – RSO) is a nationwide, free service of the Polish Ministry of the Interior and Administration that enables the notification of citizens about threats. Information is delivered via a mobile application, the websites of provincial offices, news tickers on television, and hybrid television. The Government Centre for Security (*Rządowe Centrum Bezpieczeństwa* – RCB) supports the Prime Minister and the Government Crisis Management Team in Poland in managing crises. Its main functions include coordinating national crisis response, monitoring and assessing threats to state security, operating the ALERT RCB system to inform citizens of hazards such as storms or floods, and running educational campaigns like the Safety Academy to teach the public how to respond to emergencies [translator's note].