New Technologies in Enhancing Training for Fire Service in Wildfire Response The SILVANUS Approach

FIRE UNIVERSITY

Paweł Gromek

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Introduction

Wildfire is an uncontrolled physico-chemical combustion process that occurs in the woods. It has the potential to cause harm to humans and damage to property and the environment, including impacts on key utilitarian values (Majlingova et al., 2022). It could therefore cause an emergency, a disaster (in the terminology used internationally by the United Nations), a crisis situation or even a crisis (a turning point in a crisis/disaster situation, after which irreversible changes occur in the system being experienced). A wildfire therefore meets the definitional prerequisites of a crisis threat and a potential cause of a disaster (UNDRR-ISC, 2021; GAR, 2022).

Wildlife risks are on the rise on a global scale. It is consequence of an increasing number of fires in the woods being recorded globally, as well as the growing severity of their effects. This is fostered, among other things, by climate change, the inevitability of which is due to natural cycles and human activity (anthropopressure on the natural environment) (Ma et al., 2022).

Specifics of a wildfire, its direct relation to the most important utilitarian values and its emerging role as a disaster trigger generate the necessity of enhancing preparation and pre-planning activities in wildfire response (SILVANUS, 2024). Fire service is the key actor in the analysed context. Firefighters are on the front line when a wildfire occurs. Their preparation for operational activities is crucial for effective putting out of a fire, reducing the risk of secondary hazards and threats, evacuating people in danger, and protecting critical infrastructure placed in the woods. It is worth highlighting that the response effectiveness depends also on deployment of new technologies. Drones, robots, sensors, cameras, computational tools and decision support systems are the only selected solutions that are accessible on the market; they are being constantly developed and are being used more and more frequently in the operational domain of the fire service (Pantya, 2015; Feltynowski, Zawistowski, 2018; Rejeb et al., 2021). They may differ by region or country in a way that reflects safety and security issues related to fires and other disaster triggers. It also determines special vehicles and equipment used in fire operations (Pantya 2023). Consequently, firefighters have access to new technologies with potential to facilitate wildfire response. This leverages training activities.

Training for firefighters has a primary role in preparing for wildfire response. Knowledge gained and skills acquired during studies and/or courses need to be confronted with difficult terrain conditions in the woods, specifics of a wildfire, and previous firefighting experiences. This is of key importance to ensuring a highly effective response, while also achieving optimum personal safety for firefighters in the woods. Nevertheless, new technologies can both facilitate and hinder training processes. Firstly, modern technological tools and solutions are able to automate certain activities (smoke detection, flame detection, etc.), perform them vicariously for firefighters (for example, fire monitoring), support the performance of coordination tasks (for example, by means of a fixed communication network) and improve the safety level of personnel deployed to the scene of a fire (drone and/or robotic reconnaissance). Yet secondly, new technologies also entail new operational activities in their usage during a training, and an increased level of training complexity. The support of technical staff can prove to be necessary as well. These are needs articulated to guide research efforts to combine the needs and expectations of firefighters and the potential of technology providers to improve firefighter training in fire response.

The peculiar dissonance between advantages and disadvantages related to the use of new technologies in enhancing training for fire service in wildfire response has not been fully addressed in the literature so far (ScienceDirect, 2024). As regards the specified needs, results of the studies to date are incomplete, scattered, and correspond to training curricula in a limited way. The dissonance can be addressed through comprehensive research. From the utilitarian point of view, the research should consider technology development trends, potential to integrate them on a single platform, the training process or approach, detail indications to deploy the technologies to training curricula, enhancement capabilities to both wildfire response and technologies, and personal safety issues (Gromek, 2021). In addition, firefighters pay particular attention to technology functionalities rather than on the technical details. Consequently, the technologies need to be analysed from the perspective of functionalities to provide firefighters with information on how and in what circumstances relevant tools and solutions may be used during wildfire response.

The research objective was to develop a comprehensive approach to the use of new technologies in enhancing training for the fire service in wildfire response. The research problem was formulated as the following question: What approach does allow effective and comprehensive implementation of new technologies in enhancing training for fire service in wildfire response? As regards the research hypothesis, it was assumed that the effective and comprehensive implementation of new technologies in enhancing training for fire service in wildfire response requires taking into consideration the specifics of the technology (so-called 'technologies in a nutshell'), operational protocols on how to apply technologies in training, as well as reflect two essential viewpoints of the enhancement (the perspective of firefighters and the point of view of technology providers), as well as personal safety issues.

The monograph comprises research results obtained exclusively by the author while participating in the international research and development project entitled 'Integrated Technological and Information Platform for Wildfire Management' (SILVANUS). This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 101037247. The author was the team leader at the Main School of Fire Service (Fire University), which was a partner in the project consortium. The Author's specific roles included leading and executing project tasks T3.3 Preparation and pre-planning activities for wildfire response and T9.6 Pilot outcome assessment and replicability studies. The results are directly related to these tasks. The research was based on a review of information compiled on the webpage and public deliverables of the project (SILVANUS, 2024), literature review (ScienceDirect, 2024), analysis of training standards in Poland and other countries, participatory observations carried out during the project pilots in the Slovak Republic, Indonesia and Australia in 2023, as well as consultations with firefighters who organise, carry out and participate in firefighting actions in wildfire response.

Chapter 1 provides a general background to the research, which looks at training firefighters using technology to improve preparedness activities and pre-planning of fire responses. Special attention is paid to the specifics of response. Relevant definitions are discussed and various types are presented. The author illustrates a division of the wildfire scene into several specific parts to make references to organisation of the scene. Wildfire response is presented in a wide context. Firefighting action, protection from smoke, environment protection, crisis communication, evacuation, property preparation and critical infrastructure protections constitute the response domain. The central role of firefighting action is highlighted. In addition, the SILVANUS approach to training in preparation and pre-planning activities for wildfire response is discussed. The general project approach provides an effective framework for the implementation of new technologies in training processes and enables connecting three essential training perspectives: technology, organisation and societal involvement. The project delivers 24 technological tools and solutions with potential for deployment in wildfire management. The Author focuses on 17 tools and solutions with the highest usefulness in the context of wildfire response. General implementation guidelines are presented as well.

Chapter 2 deals with reference detection technologies in enhancement of the preparation and pre-planning activities for wildfire response connected with training of firefighters. They comprise fire detection using IoT devices, fire detection at the Edge and fire detection based on social sensing. It has been confirmed that the Internet is an excellent medium for collecting, sharing and disseminating the information needed to detect a forest fire. It may connect responders and people in danger, also with the use of multiple detectors, sensors and mobile applications (including social media). It is important to ensure that the information is reliable and to reduce false positives. Research results prove that many solutions and tools are applicable in the first phase of fire response and are able to support firefighters when detecting and communicating a hazard.

Chapter 3 focuses on enhancement of the preparation and pre-planning activities for wildfire response with the use of reference computational tools connected with firefighter training. The tools are valuable to allow transforming data compiled in the woods into information useful for firefighters when they plan and conduct wildfire response activities. They are the biodiversity profile mobile app (Woode), fire hazard risk assessment and fire spread forecast. They provide the information necessary for situational awareness and allow simulating fire conditions to analyse the hazard situation in the near future. The tools carry out calculations to obtain information crucial for firefighters to plan wildfire response, respecting location of responders and their resources, and operational priorities based on fire probability and risk. In this way, the results of calculations can feed into other technological solutions, for example decision support systems.

Chapter 4 concerns enhancing the preparation and pre-planning activities for wildfire response with the use of reference operational end-technology tools connected with firefighter training. End-technology tools mean all equipment, sensors and hardware that are at the first line of response, as a rule directly in the danger zone. They support firefighters in their activities at the scene. They comprise UAV (drones), UGV (robots), Forward Command Centre, and MESH-in-the-Sky (a kind of mesh technology that is comprised by a set of elements that give commonly enhanced communication abilities). The first two are universal platforms for other technological tools and solutions. The command centre increases communicational and coordination potential of the response. The latter one is a kind of communication network that provides access to information despite hard terrain conditions and other constrains. This is especially important in the woods where firefighters need to make simultaneously effective reconnaissance, carry out firefighting action, consider secondary threats, monitor the hazard situation, and cooperate with other wildfire responders.

Chapter 5 addresses enhancing the preparation and pre-planning activities for wildfire response with the use of decision support systems that address firefighter training. The systems are said to state information environment in which proper, actual, quick and rational decisions can be made. The SILVANUS project delivers four solutions that can effectively support wildfire response conducted by firefighters, and namely the Multilingual Forest Fire Alert System, the Resource Allocation of Response Teams, the Priority Resource Allocation based on Forest Fire Probability and the Evacuation Route Planning. The technologies make use of data fusion, machine learning, deep learning and simulations to suggest alternative decisions on topics expressed in their names. Firefighters can be informed about fire locations, probabilities and fire risk to deploy resources in places where they are mostly needed or where they could be needed. In turn, evacuation planning is helpful when analysing overall response to the wildfire, arrival routes and emergency routes (for people in danger, including firefighters).

Chapter 6 addresses enhancing the preparation and pre-planning activities for wildfire response with the use of reference societal involvement tools connected with firefighter training. The important role of citizens and fire service personnel is highlighted. Their preparation for wildfire response is essential to make the response effective. New technologies may facilitate the achievement of this objective. Three reference technologies are described, and namely augmented reality training for firefighters, citizen engagement application and the IT Dashboard. This demonstrates the complexity of solutions and tools that can ensure close collaboration between fire services and other stakeholders and increase the level of preparedness for a wide range of users.

Every chapter is structured to present the technology in a nutshell, relevant operational protocol, enhancement capabilities, as well as safety issues. This exemplifies the morphological analysis (each technology is and allows complex and comprehensive research. Consequently, general context of the technology use is described, including, as appropriate, how to use it during a training, what are advantages and implementation risks related to the technology, as well as what factors may determine personal safety of trainees and how to face them.

The Author strongly hopes that the research results presented in this monograph will prove to be of interest to training organisers, firefighters and technology providers who work on enhancing the preparation and pre-planning potential in wildfire response. Our heartfelt gratitude goes to the to the SILVANUS partners for their fruitful cooperation, numerous inspirations and the conviction that the project was the good work done.

Chapter 1

Technology-determined training for firefighters to enhance preparation and pre-planning activities for wildfire response

1.1. Specifics of wildfire response

A wildfire is a kind of fire that occurs in afforested areas that comprise open land overgrown with grass, brush or trees (Majlingova et al., 2022). These are specific combustible materials and their accumulation can mean a high fire load on the site. Furthermore, the fire may affect typically people (inhabitants, forest workers, tourists, etc.) and the environment (biomass, soil, forest water resources, wild animals, air). Consequently, a wildfire is defined as uncontrolled and unpredictable burning or combustion of plants in a natural environment, such as a forest, grassland, scrub or tundra, which consumes natural fuels and spreads under the influence of environmental conditions (e.g. wind, topography)(EUFOFINET, 2012; CIFFC Glossary, 2022). A wildfire is called differently in different countries. It is also called a forest fire, a bushfire, a vegetation fire, or just a fire of the woods.

Wildfires are classified according to the location of occurrence and coverage of forest stand. Figure 1 presents general overview on wildfire placement in the woods.

There are the following types of a wildfire (Szczygieł, 2017; Majlingova, 2024):

a) a ground fire (also called an underground fire, or a subsurface fire) – it occurs in deep accumulations of humus, peat and other kinds of dead vegetation that is dry enough to initiate and sustain combustion,
b) a surface fire – it occurs in the woods due to burning of combustible materials accumulated on the ground (dry grass, fallen leaves, dry needles, low trees, snags, bark waste, lying sticks, lying logs and dry wood),
c) a crown fire – it covers crowns of trees and often entire trees, may develop rapidly and is often initiated by ground fires and surface fires,
d) a hollow tree fire – it affects a single tree and is typically a consequence of a lighting or a setting a fire,

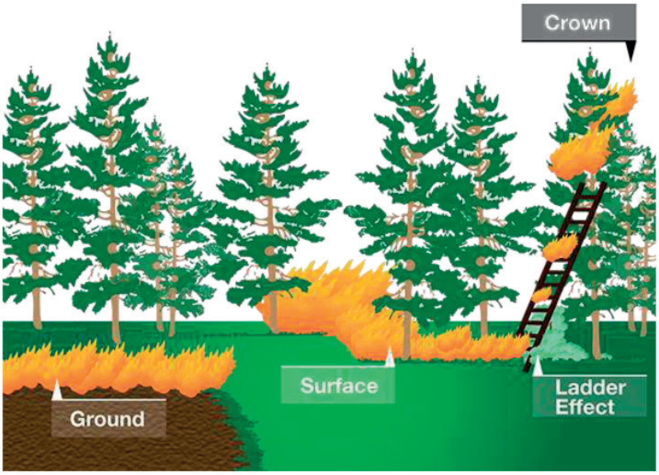

Figure 1. IoT element designed to detect a wildfire
Source: (Majlingova et al., 2022)

e) a total forest stand fire – it covers the entire volume of combustible materials on the surface and above the surface in the woods and means total losses in biomass.

From an operational point of view, the fire scene is divided into the following several specific parts:

a) tail – a place typically close to the ignition point where a fire has started,
b) right flank – the right side of wildfire scene taking into consideration the wind direction,
c) left flank – the left side of wildfire scene in relation to the wind direction,
d) island – an area bypassed by a fire,
e) finger – an area of highly intensive burning,
f) pocket – an area of low intensive burning,
g) spot fire – a hot spot outside the main fire compartment (for example generated by a sail),
h) head (also called a front) – an area characterised by the highest intensity of burning.

Specific parts of wildfire scene are illustrated in Figure 2.

In general, wildfire response relies on conducting activities intended to eliminate or minimise the adverse impact of wildfire manifestations (flames, thermal radiation, smoke) on humans, animals, property, infrastructure and resources of natural environment. This can be done by:

a) firefighting action (direct putting out the fire),
b) mass evacuation of people (the emergency evacuation and/or the preventive evacuation),

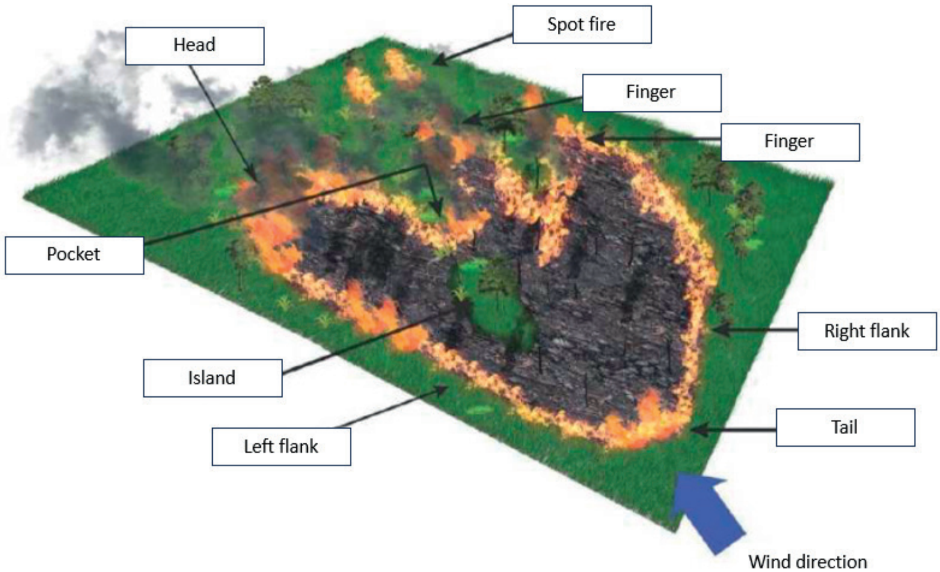

Figure 2. Specific parts of wildfire scene
Source: own study on the basis of (Monosi et al., 2015)

c) critical infrastructure protection,
d) preparing property for an impending fire,
e) providing protection from smoke,
f) environment protection,
g) crisis communication between safety entities and between the entities and the people in danger (including warning and informing people about the hazard that has already materialised).

An analysis of above-mentioned issues proves that wildfire response may exceed the scope of firefighting operations and the wildfire scene may be wider that the direct danger zone (it may apply to shelters situated far from wildfire manifestations). The firefighting operation is the core of the response, but should be strongly linked to other elements of the response to ensure their comprehensiveness and facilitate their coordination. It is schematically illustrated in Figure 3.

Consequently, although the fire service is regarded as the major operational actor, it is not the only one that can be involved in responding to a wildfire. It is hard to imagine that firefighters are quantitatively and qualitatively adequate to cover the entire domain of wildfire response. This is clearly impossible due to resource constraints and noticeable especially when multiple fires occurred at the same time and/or a multi-hazard event occurred. The fire brigade is primarily involved in firefighting operations. From the practical viewpoint, it is often supported by forest service, public administration, armed forces, police troops and voluntary entities,

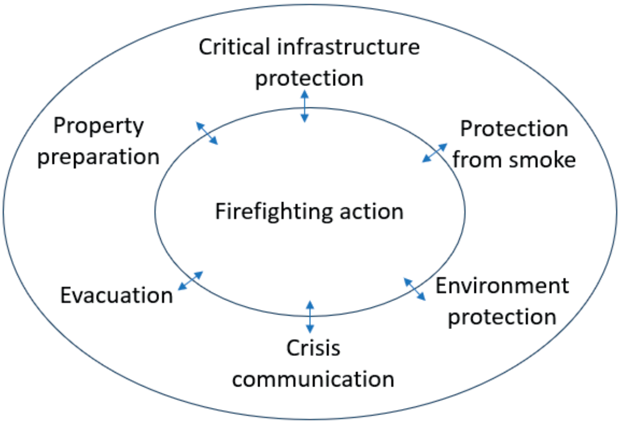

Figure 3. Set of general wildfire response activities
Source: own study

and the supporting entities are to conduct notably the remaining type of activities. Consequently, wildfire response appears as a job in cooperation. Openness on multi-entity efforts is highly desirable.

Every element of the wildfire response domain can be divided into sub-domains and activities to express more deeply specifics of the response. The domain can be detailed inter alia as follows:

1) as regards the firefighting action (direct fire extinguishing):
   a) early detection and communication of the hazard,
   b) immediate dispatch of wildfire responders,
   c) effective delivery of the resources to the wildfire scene,
   d) comprehensive reconnaissance of hazard situation (from the ground and from the air),
   e) firefighting tactics,
   f) cooperation between firefighting entities;
2) as regards mass evacuation of people (emergency evacuation and/or preventive evacuation):
   a) analysing the range of wildfire manifestations (flames, smoke, thermal radiation),
   b) analysis of secondary hazards and threats to a wildfire,
   c) designation of the danger zone,
   d) analysis of road network and shelters (these outside the danger zone and shelters localised inside it[1]),
   e) designation of evacuation roads and shelters,

[1] For example, for the purposes of emergency evacuation of firefighters due to dynamic development of hazards.

   f) dispatching entities to manage evacuation and support people,
   g) returning home;
3) as regards critical infrastructure protection:
   a) analysing the range of wildfire manifestations (flames, smoke, thermal radiation),
   b) analysis secondary hazards and threats to a wildfire,
   c) dispatching entities to support critical infrastructure protection (to ensure its operational continuity),
   d) cooperation with critical infrastructure operators;
4) as regards preparing property for an impending fire:
   a) analysing the range of wildfire manifestations (flames, smoke, thermal radiation),
   b) analysing secondary hazards and threats of a wildfire,
   c) instructing people on how to prepare their property for an impending fire,
   d) warning people about the need of preparing property for an impending fire,
   e) ensuring means and methods for the preparation (water tanks, soil demineralisation equipment, heavy construction equipment, firefighting hoses, pumps, etc.);
5) as regards protection from smoke:
   a) analysing the range of wildfire manifestation (smoke),
   b) warning people about the need of protecting themselves from smoke,
   c) instructing people on how to protect themselves from smoke,
   d) ensuring means and methods for the protection (for example masks);
6) as regards environment protection:
   a) analysing the range of wildfire manifestations (flames, smoke, thermal radiation),
   b) analysing the secondary hazards and threats posed by a wildfire,
   c) indicating environmental resources already affected and predicted to be affected by the manifestations of the fires and the corresponding secondary hazards and risks,
   d) dispatching entities to protect the environment against wildfire manifestations, as well as secondary hazards and threats,
   e) initiating build-back-better strategies to enhance forest resilience;
7) as regards crisis communication between safety entities and between the entities and people in danger (including warning and informing people about a hazard that has already materialised):
   a) collecting information about a wildfire, its conditions, consequences, operational needs, humanitarian needs, and response operations conducted,
   b) forming a picture of the situation,
   c) sharing information with dedicated entities.

Specific response activities may vary depending on the type of wildfire and the relevant location on the wildfire scene. This becomes most noticeable in firefighting operations, as firefighting tactics are largely determined by type and deployment. In general, the response starts with compiling information to devise a background for decision-making processes. As a rule, wildfire response is based on shaping a reliable operational picture and making rational decisions on kinds of activities to be carried out and entities to be involved. A particular important issue is to focus not only on a preliminary hazard (the fire itself) and its manifestations (such as flames, thermal radiation, smoke) but also on secondary hazards and threats. A wildfire may be an integral element of a complex set of disaster triggers. It can be triggered by other factors and play a triggering role in other types of disasters (Gromek, 2023).

In addition, many of these activities can be supported by multiple technologies, tools and solutions. This is reasonable from the perspectives of raising situational awareness, ensuring personal safety for wildfire responders (for example firefighters who operate directly in the danger zone), and supporting security-related systems (forest protection system, fire protection system, firefighting rescue system, an emergency management system, disaster management system, crisis management system, etc.). In accordance with a literature review (ScienceDirect, 2024), the following technologies can be enumerated:

a) machine learning,
b) deep learning,
c) computational neural networks,
d) artificial intelligence,
e) smoke detectors,
f) flame sensors,
g) thermal sensors,
h) Internet of Things (IoT),
i) Big Data analysis,
j) data fusion,
k) remote sensing,
l) social sensing,
m) unmanned aerial vehicles (UAV),
n) unmanned ground vehicles (UGV),
o) firefighting vehicles and posts,
p) optimisation algorithms and models,
q) visualization and mapping tools (including geospatial information systems, GIS),
r) Wi-Fi technologies,
s) satellite technologies,
t) GSM technologies,
u) radio technologies,

v) technologies to integrate communication process,
w) fire spread modelling,
x) fire spread forecasting,
y) evacuation simulators,
z) decision support systems.

Some of the solutions are based on two or more technologies to ensure a synergistic effect when using them for wildfire response purposes. This means that wildfire response technosphere is gaining importance nowadays. Technology development may foster efficiency of the response. However, this requires effective handling of multiple tools by end-users. This could prove to be complicated because of their number, differentiation and complexity.

Training for firefighters appears to meet the reported challenges. This can enhance preparedness and pre-planning of fire response activities, focusing on the most important group of responders (namely firefighters), while being open to involving other actors in training processes. Training scenarios may concern all types of wildfires and an entire spectrum of their conditions (including the location of the danger zone and coverage of the forest stand). And finally, training for firefighters is capable of implementing new technologies. This could suggest that some operations may be done quicker, safer and more effectively.

1.2. SILVANUS approach to training in preparation and pre-planning activities for wildfire response

Training for firefighters is so important for preparation and pre-planning activities in wildfire response that it has been taken into consideration in international research and development projects for many years. For example, there have been 17 wildfire-related projects with training activities considered directly or indirectly in EU since 2017 (CORDIS, 2024). One of the last significant ones and the reference one is SILVANUS (Integrated technological and Information Platform for wildfire management, grant number 101037247) (SILVANUS, 2024).

"SILVANUS envisages to deliver an environmentally sustainable and climate resilient forest management platform through innovative capabilities to prevent and combat against the ignition and spread of forest fires. The platform will cater to the demands of efficient resource utilisation and provide protection against threats of wildfires encountered globally. The project will establish synergies between (i) environmental; (ii) technology and (iii) social science experts for enhancing the ability of regional and national authorities to monitor forest resources, evaluate biodiversity, generate more accurate fire risk indicators and promote safety regulations among citizens through awareness campaigns. The novelty of SILVANUS lies in the development and integration of advanced semantic technologies to systematically formalise the knowledge of forest administration and resource utilisation. Additionally, the platform will integrate a big-data processing framework capable of analysing heterogeneous data sources including earth observation resources, climate models and weather data, continuous on-board computation of multi-spectral video streams. Also, the project integrates a series of sensor and actuator technologies using innovative wireless communication infrastructure through the coordination of aerial vehicles and ground robots" (CORDIS, 2024).

Particular attention in the project is placed on close cooperation with end-users, especially with firefighters. This corresponds to their role in the overall process of wildfire response. The project connects three essential layers of wildfire management – the management organisation, its technosphere, and societal involvement. Such a way of conducing project efforts ensures that the work is synergy-oriented. The management concerns different management standards and approaches adopted in different countries, and determines a good framework for moderation of cooperation between multiple entities. New technological solutions are analysed in terms of their effective use in management, also by facing specific operational needs reported by firefighters. The significant role of people is highlighted as users of the woods are typically first on the wildfire scene. They are able to shorten the time between fire ignition and informing wildfire responders. They can be also affected by wildfire manifestations so direct communication to potential victims is crucial in the context analysed. All these issues may be reflected in training for firefighters. This is illustrated by Figure 4.

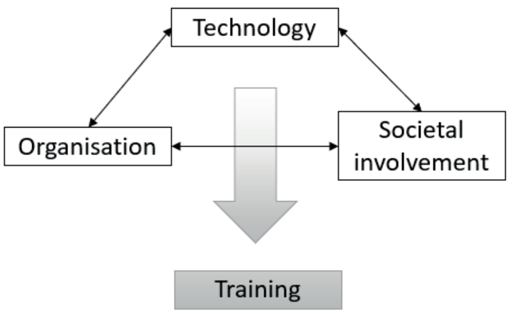

Figure 4. Relation between training for firefighters and essential layers of wildfire management

Source: own study

Technology seems to integrate organisation and community engagement unevenly when we speak of training firefighters in the preparation and pre-planning of responses to fires. Organisational standards are determined by accessible technologies – their advantages and disadvantages, functionalities, and practical limits. Technologies connect security entities to citizens and ensure information flows between these two groups of stakeholders. As an effect, technology is said to be a valuable cognitive aspect of practical implementation of new knowledge and skills to practice through training for firefighters.

The SILVANUS consortium conducted a broad technology investigation to indicate tools and solutions that are characterised by the highest potential to improve wildfire management and the highest probability for technology integration to a single technological platform. This allowed the selection and development of the following technologies, called user products in the project (SILVANUS, 2024):

1) User Product 1 – Augmented Reality / Virtual Reality Training for Firefighters (to frame simulated reality for training of firefighters in quasi-real environment).
2) User Product 2 – Fire Danger Tool (to estimate the level of danger basing on accessible data).
3) User Product 3 – Fire Detection based on Social Sensing (to integrate and use social tools to communicate a fire).
4) User Product 4 – Fire Detection from IoT Devices (to connect IoT devices into a detection network).
5) User Product 4b – Fire Detection at the Edge (to work out a detection network to integrate different and cognitively valuable technologies).
6) User Product 5 – Fire Inspection using UAVs (Drones) (to use drones for inspection and monitoring activities).
7) User Product 6 – Fire Inspection using UGVs (Robots) (to use robots for inspection and monitoring activities).
8) User Product 7 – Fire Spread Forecast (to simulate the development of a wildfire and make the relevant forecast).
9) User Product 8 – Biodiversity Profile Mobile App (to analyse biodiversity in the given area as well as to use this knowledge in an analysis of vulnerability of the woods to a wildfire).
10) User Product 9 – Citizen Engagement Mobile App (to develop an effective communication and educational tool for citizens to make them useful and to make stakeholders self-sufficient in terms of wildfire management).
11) User Product 9a – Decision Support System - Resource Allocation of Response teams (to facilitate response planning on the basis of resource allocation in terms of wildfire risk).
12) User Product 9b – Decision Support System - Health Impact Assessment (to analyse wildfire indicators as regards prediction of health consequences for people in danger).
13) User Product 9c – Decision Support System - Evacuation Route Planning (to analyse evacuation conditions and suggest proper evacuation routes when planning wildfire response).

14) User Product 9d – Decision Support System - Continuous Monitoring of Rehabilitation Strategy Index (to parametrise rehabilitation strategy for the woods and to monitor the relevant process).
15) User Product 9e – Decision Support System - Ecological Resilience Index (to parametrise the ecological ability of the woods exposed to a wildfire to resist, absorb, accommodate, adapt to, transform and recover from the effects of this kind of hazard in a timely and efficient manner).
16) User Product 9f – Decision Support System – Biodiversity Index Calculation (to raise situational awareness on potential fire load in the given area).
17) User Product 9g – Decision Support System - Soil Erosion Index (to assess and predict soil erosion in the woods, with particular attention on the woods impacted by wildfires).
18) User Product 9h – Decision Support System - Integrated Data Insights (to improve decision-making processes during wildfire emergencies by utilising the combined knowledge collected in the project).
19) User Product 9i – Decision Support System - Forest Fire Alert System (to automate fire alerting processes in terms of wildfire and to make early warning possible).
20) User Product 9j – Decision Support System - Priority Resource Allocation (to calculate the probability of a wildfire in a given area and to indicate places characterised by high priority to allocate response resources on the field).
21) User Product 9k – Decision Support System - Deep Learning Model for Wildfire Severity Prediction (to analyse wildfire severity scenarios on the basis of deep learning to feed decision-making processes).
22) User Product 10 – Forward Command Centre (to facilitate wildfire responders in the effective organisation of response, managing crisis communication and using new technologies in an integrated way).
23) User Product 11 – SILVANUS Dashboard (to functionally integrate IT solutions useful for wildfire management and to make situational picture complete).
24) User Product 12 – MESH-in-the-Sky (to ensure effective communication conditions in the woods despite of the communication constraints).

The technologies may be deployed to wildfire management in multiple ways. SILVANUS places the order in a technology application for management purposes. Consequently, three essential wildfire management phases have been specified:

a) Phase A – prevention and preparedness,
b) Phase B – detection and response,
c) Phase C – restoration and adaptation.

The phases essentially ascribe into the general process of disaster management. This is shown in Figure 5.

It is difficult to establish conclusively which phases are more or less important. However, the response (Phase B) seems to be the most impressive, medial, shaping

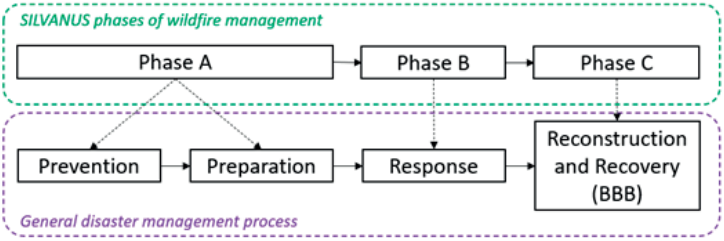

Figure 5. SILVANUS wildfire management phases and the general process of disaster management
where: BBB build-back-better
Source: own study

sense of safety, and determining political decisions. On the one hand, the response is not separated from other management phases. Prevention and preparedness should allow creating foundations for effective response. And the response needs to structure the wildfire scene to make restoration and adaptation possible. It is therefore prudent to consider Phase B as a major component of the overall wildfire management process. Training activities should consider this phase directly (for example by enhancement of firefighting skills and abilities) or indirectly (for instance by preparing proper conditions for arrival of fire vehicles to the response scene). Furthermore, training for firefighters in preparation and pre-planning activities in wildfire response should serve as reference for other types of training related to wildfire management.

The positioning and specificity of fire response in the overall fire management process influences fire training to improve preparation and pre-planning activities with the use of new technologies. On the basis of observations conducted by the author during SILVANUS pilot events, the following guidelines should be taken into account:

1) Training curricula should enable the use of new technologies in educational processes for firefighters.
2) Training scenario should be technology-determined and some of the scenario elements need to be technology-related (for example fire detection activities, creating situational awareness via reconnaissance).
3) Technologies must be characterised by functionalities that reflect operational needs of firefighters. This means the necessity of indicating specific firefighting activities to be facilitated by technological tools and solutions.
4) The training process should be organised in such a way as to demonstrate that new technologies facilitate fire response. This is particularly noticeable in terms of shortening response operations, automating them, increasing the personal safety of firefighters, saving expensive firefighting equipment, etc.

5) It is a good practice to involve firefighting entities in training organisation to optimise organisational efforts that need to reflect training assumptions, technological advantages and disadvantages, as well as operational needs of firefighters.
6) The complexity level of technologies must be adjusted to cognitive skills and abilities of users.
7) Technical support for trainees is essential to ensure that their mental burden is reduced and to make the training effective.
8) Trainers must be prepared to support trainees in using technologies and interpreting the results of their use.
9) Tools that enable shaping situational awareness should be integrated to visualisation solutions. The good practice is to develop an IT desktop and to functionally connect it to GIS technologies.
10) Shaping situational awareness requires that the same situational picture is accessible (for example with the use of IT desktop) to all main decision-making actors (commanders, managers, action staff members). The need to deploy a forward command centre is highlighted.

The above guidelines can be used to concretise the requirements for training firefighters in responding to technology-driven fires. What is more, the SILVANUS technologies can direct training efforts. This is reasonable because user products reflect the current status of technologies that are sufficiently mature to be deployed to response activities and can be technically and/or functionally integrated.

1.3. General implementation of new technologies for training purposes

SILVANUS technologies are associated with wildfire management regarding three essential management phases: Phase A – prevention and preparedness; Phase B – detection and response, and Phase C – restoration and adaptation. This determined the choice of technologies that define user products. However, not all of them are proper for the purposes of wildfire response and additionally face operational needs of firefighters. In general, user products dedicated to Phase B give the highest value in the context under consideration.

Taking into account the needs of firefighters and focusing on the specifics of firefighting actions, the following user products should be considered when analysing new technologies aimed at enhancing training for fire service in wildfire response[2]:

[2] The selection process for SILVANUS user products was carried out by the author through consultation with other members of the Fire University team in the SILVANUS project and firefighters who have conducted firefighting operations in the woods.

1) as regards detection technologies:
   a) fire detection using IoT devices,
   b) fire detection at the Edge (by implementation devices that are situated directly on the wildfire scene or near the scene on the ending of organisation of firefighting action),
   c) fire detection by social sensing;
2) as regards computational tools:
   a) biodiversity profile mobile app,
   b) fire danger risk assessment,
   c) fire spread forecast;
3) as regards end-technology tools:
   a) fire monitoring using UAVs (drones),
   b) use of UGVs (robots),
   c) Forward Command Centre,
   d) MESH-in-the-Sky;
4) as regards decision support systems:
   a) Multilingual Forest Fire Alert System,
   b) Resource Allocation of Response Teams,
   c) Priority Resource Allocation based on Forest Fire Probability,
   d) Evacuation Route Planning;
5) as regards societal involvement tools:
   a) augmented reality / virtual reality training for firefighters,
   b) citizen engagement application,
   c) IT Dashboard.

Detection technologies play a primary role in ensuring that wildfire response is started as soon as possible, and the relevant alarm is not a false-positive one. This is of great importance when wildfire risk level is relatively high (for instance due to so called 'the fire weather') and the responders may be forced to handle many hotspots in different places at the same time. Their optimal use in such circumstances is crucial to effectively confront the risks. Particular attention should be paid to the implementation of multiple detection tools to cross-check them, and to ascertain where fire service resources are really needed.

Fire detection is the first step when shaping a situational picture related to a wildfire in the woods. The second one is compiling as much information as possible to be aware of what has happened, what is happening, and what could happen during the nearest hours. In addition, the information must be reliable, complete and actual. This may be done by reconnaissance activities conducted by firefighters on the scene as well as by analytics located far from the field. Computational tools are crucial to analyse the collected data and to obtain new information necessary to make rational response decisions.

End-technology tools are technology platforms designed to collect data and information, replace firefighters in some activities, and to facilitate organisation of the response process. Drones and robots can be used to support firefighters in some of these activities (for example by playing a role of a quasi-independent firefighting post or an evacuation platform). They can also be integrated with detection technologies. The technology integration potential seems to be very high when considering Forward Command Centre and MESH-in-the-Sky. The first one can significantly strengthen the coordination of the response. The second one is able to state communication structure and connect multiple responders into a single communication network. This may also allow covering terrains characterised by communication constrains.

Decision support systems are technological solutions that directly support decision-making processes. They find application when advanced analytical needs are noticed and computational tools need to be integrated in the given (decision-determined) direction. Even if the responsibility for the results of decisions rests with the commander or the manager (emergency manager, disaster manager, crisis manager), the system can suggest alternative actions and ensures the choice opportunity. The very valuable aspects of complex decision making are optimal resource allocation and evacuation planning.

Wildfire response is not placed in a societal vacuum. The hazard has an impact on people, and people can play a significant role in responding to it. The augmented reality / virtual reality training for firefighters, citizen engagement application, and IT Dashboard support this statement. Their use can be related to societal involvement and multiple kinds of users (not only firefighters) may be beneficiaries of those solutions. Proper understanding of these relationships is essential to optimising wildfire response and making technologies universally useful in the context under consideration.

The outcome of the choice of technology does not mean that other fire management tools and solutions should be overlooked. They may be useful but not necessarily to firefighters in the specific perspective of wildfire response. This could include developing forest restoration strategies in line with the build-back-better concept, monitoring the effectiveness of strategies, analysing short- and long-term health impacts, shaping ecological resilience, etc.

As regards observations conducted during the SILVANUS demonstration events, the general implementation of new technologies for the training purposes requires focusing on the following issues:

a) specifics of the technology,
b) operational protocol of the technology use,
c) enhancement capabilities,
d) safety issues related to the technology deployment.

Every technology is unique in nature. For example, decision support systems are typically IT solutions. They require integration with computational tools. The cognitively valuable functionality is to also integrate them to visualisation solutions (GIS, other mapping applications). If the systems are not manually complex, only limited technical support is necessary. The situation is quite opposite in case if the so-called 'hard technologies'. The use of UAVs, UGVs or technically advanced sensors causes the necessity to ensure technical staff to support trainees when they carry out training activities. When analysing the specifics of technology related to the training of firefighters in technology in order to streamline preparatory activities and pre-planning for fire response, particular attention should be paid to the general technological background (state of the art, development trends, etc.), main beneficiaries and the most valuable functionalities. The functionalities seem to be the most important aspects of technology use given operational needs and expectations of firefighters. This is valid in case of the training and, especially, during real firefighting action in the woods.

Raising awareness as to the functionality of technologies is the first step to using them in a purposeful, rational and efficient manner. The next step relies on integration of the technology into the overall firefighting process. This is why operational protocol of the technology use should refer to a universal process of wildfire response. The process comprises the following:

a) early detection and communication of the hazard,
b) immediate dispatch of wildfire responders,
c) effective deployment of the resources to the wildfire scene,
d) comprehensive reconnaissance of hazard situation (from the ground and from the air),
e) firefighting tactics,
f) cooperation between firefighting entities.

Technology specifics leverage the scope of the response that may be supported by a particular technology. From the practical point of view, it is valuable to indicate activities to be conducted by firefighters during training designed to highlight that relevant tools and solutions have a positive potential to facilitate the response, make it quicker, safer, more complex, more effective, etc. In some cases, detailed information on the steps of using technology can be of value to effectively implement it for training purposes. This is noticeable when tools and solutions are manually complex and support from technology staff is limited.

Implementation of new technologies for training purposes is challenging as it requires combining two essentially different perspectives – the one of firefighters' and that of technology providers. Those two groups of stakeholders differ in backgrounds, goals, needs and expectations, and use different languages to describe the same reality. The challenge is to integrate them sufficiently to develop a technology that is useful for firefighters and allows further improvements and wider implementation. Consequently, emphasizing enhancement capabilities is crucial to convince the need of the implementation as well as the necessity of adjusting tools and solutions to specific end-users. It is not free from factors that may impede the implementation and are able to generate operational risks. However, potential benefits of the use of technologies for training purposes justify the need of facing those risks.

Lastly, training for firefighters is a risky venture. It involves specific training conditions, including difficult terrain conditions, use of multiple equipment and devices, complexity of training activities, uncertainty in decision-making processes, situational stress, necessity of cooperating with multiple responders, etc. This is why safety issues for the deployment of technology are necessary to consider. Potential sources of personal risks may be different. They could be (i.a.):

a) hazards of moving, loose and protruding parts,
b) movement of people and equipment,
c) fall from a height,
d) electric shock,
e) fire-related hazards (thermal radiation, smoke, burn),
f) microclimate,
g) severe weather conditions,
h) noise,
i) visual radiation,
j) chemical factors,
k) biological factors,
l) mental burden.

A description of the circumstances in which these risks may materialise can help training providers, instructors and trainees to reduce the relevant personal risks. This can also have a positive impact on the overall effectiveness of training and preparation for actual firefighting operations.

A screening view of the general implementation of new technologies for training purposes highlights that the use of morphological analysis in the presentation of individual technologies is cognitively valuable and rational. The analysis means that every tool or solution selected should be described in a way that reflects relevant specifics of the technology, operational protocol of the technology use, enhancement capabilities, and safety issues related to the technology deployment. This will ensure that each description is holistic and relatively independent of other descriptions (to ensure that the description is useful to trainers and trainees), as well as enabling cross-comparison of technologies (to support training providers and technology suppliers). It is especially important when considering technology functionalities – the most important perspective of firefighters in the context under consideration.

Chapter 2

Reference detection technologies in enhancement of the preparation and pre-planning activities for wildfire response in training of firefighters

2.1. Fire detection using IoT devices

2.1.1. Technology in a nutshell

The Internet of Things (IoT) is a kind of a network comprised in physical elements (devices). The devices are being enhanced due to general technology development. This phenomenon gives rise to additional possibilities for the use IoT devices in terms of disaster preparedness and forecasting (Pallai et al., 2021), analysing of disaster scenarios (Sacco et al., 2020) and shaping virtual infrastructure for disaster situations (Abdellatif et al., 2023). IoT devices are also being deployed to detect fire disasters in vast environment of the woods (Cui, 2020). From the theoretical viewpoint, every kind of sensor can be connected to the network of physical elements (devices) and co-constitute an IoT solution.

As regards IoT that involves fire detection devices, relevant solutions may be aimed at compiling information about fire occurrence on wildland area. This information is considered to be crucial for wildfire responders and forest owners to urgently initiate rational wildfire response. As an effect, the potential technology beneficiaries are line firefighters, field commanders, forest services, forest management centres, emergency management centres, disaster management centres and crisis management centres. All these entities require reliable information about hazard location to make managerial decisions, operational decisions as well as analytical efforts to obtain a real situational picture. In accordance with IoT potential and specifics, relevant devices can be also used for training purposes.

The main functionality of IoT devices designed for fire detection is to make use of the integrated sensor to identify wildfire manifestation(s) (for example smoke, flames, hot spot). In detail, current state of technology development justifies the use of IoT devices inter alia for (SILVANUS, 2024):

1) dynamic monitoring of remote areas,
2) constant checking for fire/smoke events within the area of interest, using machine learning,
3) close monitoring of actual fire/smoke events,
4) identifying fire-prone areas,
5) databasing/documenting wildland areas,
6) developing other monitoring/preventive models (e.g., fire spread model), using the data compiled,
7) assessing fire severity,
8) improving the use and allocation of responders' resources (e. g. fire engines).

From the operational viewpoint, the tool may consist of a waterproof case, with a strap for its fastening on trees/poles, which encloses commonly used sensors and components. It can be powered by a power bank that recharges with the help of solar panels (making it fully power independent as electricity is not always available). To increase its usefulness, the device should be responsible for the collection of sensor data (e.g., humidity/temperature), capturing images of its surroundings, and processing on the spot. The tool could employ pre-trained fire and smoke detection machine learning models. Then, it can be able to assess possible fire/smoke events in the newly captured image. In the case of an identified fire/smoke event, the device is to send a warning message to wildfire management system, along with complimentary data (i.e., geo-location) and inform first responders (e.g., firefighters) (SILVANUS, 2024).

Figure 6 shows one of IoT elements designed to detect a wildfire.

Figure 6. IoT elements designed to detect a wildfire
Source: (SILVANUS, 2024)

The use of IoT devices for fire detection requires access of dedicated hardware and software. In terms of hardware, there is a lot of equipment items that may be implemented for training needs. They can be divided as follows:

1) computational unit(s),
2) detectors,
3) additional items (i. a. cables, batteries, fixings).

Figure 7 presents an illustrative set of such elements.

Figure 7. IoT items collected for one device to detect a wildfire

Source: (Catalink, 2024)

As regards software, it consists of computational mechanisms that identify and analyse measurements from detectors.

Because wildfire response is essentially determined by information about hazard location, IoT devices may be applied in training for firefighters. The information may be useful to achieve preliminary operational picture, to formulate first orders, and to ensure principal safety aspects (for example to choose arrival route that is not affected by smoke and/or flames). Awareness about the hazard occurrence and the danger zone is mandatory to initiate wildfire response. It typically states the first stage of training when wildfire scenario is implemented.

2.1.2. Operational protocol of the technology use

From the practical point of view implementation of fire detection using IoT devices needs to refer to a universal process of wildfire response. Specific relations are expected to be reflected by the implementation operational protocol. Figure 8 visualises them in a logical way.

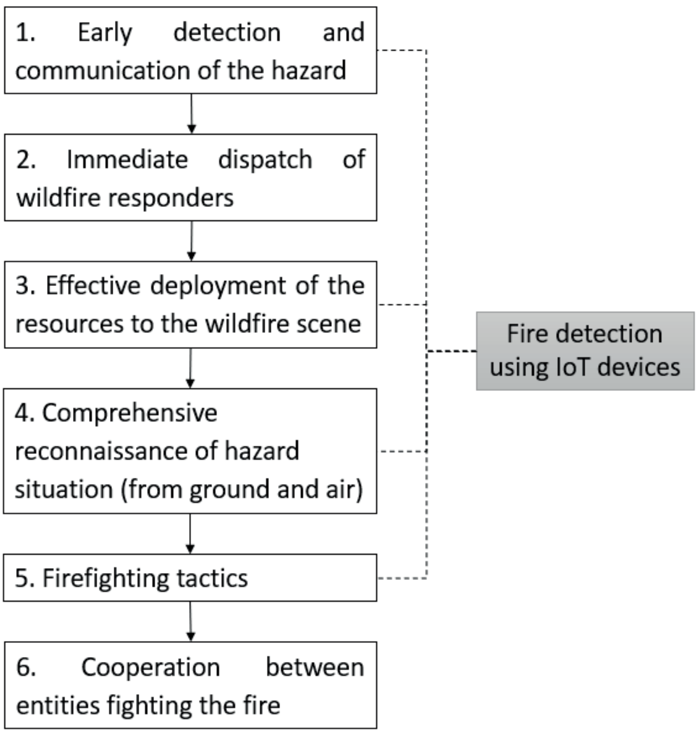

Figure 8. Deployment of fire detection using IoT devices in support of wildfire response training

Source: own study

The technology impact concerns two-thirds of phases that refer to wildfire response. They are early detection and communication of the hazard, effective delivery of resources to the wildfire scene, comprehensive reconnaissance of hazard situation (from the ground and air) and firefighting tactics. In all these cases information about fire manifestations in the woods may be of help to firefighters to make proper and quick decisions. This is why relevant information is valuable to feed decision-making processes during training. Table 1 contains examples on how to implement fire detection using IoT devices into training activities for each phase of response. Such a way of presentation concretises the operational protocol of technology use in purposes of firefighting training.

Table 1. Examples on how to implement fire detection using IoT devices into particular phases of wildfire response

No.	Phase	Examples
1	1. Early detection and reporting of the hazard	1) The trainee acknowledges the fact that a hazard has been detected. 2) Trainee verifies reliability of information regarding the fact that a hazard has occurred. 3) Trainee marks a preliminary zone where the wildfire occurred.
2	3. Effective provision of resources to the wildfire scene	1) Trainee adjusts arrival route to the wildfire scene as regards location of hotspots. 2) Trainee seeks alternative directions and access roads in case of wildfire develops as reflected in the location of hotspots.
3	4. Comprehensive reconnaissance of the hazard situation (from the ground and the air) reconnaissance (from the ground and from the air)	1) Trainee analyses wildfire scene from a general above- or below-ground perspective to gather basic reconnaissance information on hotspots location.
4	5. Firefighting tactics	1) Trainee marks the danger zone for further planning of firefighting tactics.

Source: own study

The use of IoT devices for fire detection is characterised by the same quantitative potential to support firefighting training. Differences between the sites are noticeable when talking about specific operational protocol defined by this unique technology. The operational protocol is composed by typically technical activities to be conducted by technical support staff rather than by firefighters. In accordance with information from technology provider in the SILVANUS project

(Catalink), a suitable solution requires the following steps to prepare the device (Catalink, 2024):

1) Step 1 – Insert the SD Card. Insert the SD card in the Raspberry Pi's (RPi) dedicated slot, located on the back side of the RPi.
2) Step 2 – Mount the RPi. Screw together two spacers that will be used to secure the RPi on the placeholder and later as a base for the Global System for Mobile Communications (GSM)/ Long Term Evolution (LTE) hat. To fasten the RPi, place it over the placeholder and use the spacers to secure it in the spots.
3) Step 3 – Add GPIO Pin Extenders. For the connection of the GSM/LTE Hat to the RPi, stack the GPIO pin extenders and place them on corresponding headers on the RPi.
4) Step 4 – Connect the Camera Module. To connect the camera module, locate the camera module port on the RPi and gently pull up the edges of the port's black plastic clip. Insert the camera ribbon in the port slot and push back the plastic clip in place. Similarly, take the other end of the ribbon and connect it to the camera module. That is, pull the plastic strip on the camera module and push the camera ribbon in the slot. Again, make sure the connectors are facing the contacts in the port.
5) Step 5 – Connect the GSM/LTE Hat. Append the GSM/LTE hat to the RPi by pressing it over the GPIO Pin Headers through the respective holes (as shown in the image below). Once the hat is in place, secure it with the small screws over the spacers previously used to secure the RPi.
6) Step 6 – Assemble the GSM/LTE Hat. To assemble the GSM/LTE hat at the nano SIM card (green card on right) in the dedicated slot on the left side of the hat and on the right top SMA mount, fasten the female side of the antenna cable. The antenna and the GPS will be added in later steps to make the in-case setup easier. Lastly, the USB-to-USB cable needs to be connected to the USB port of the GSM/LTE hat to the top UBS 3.0 port of the RPi.
7) Step 7 – Connect Temperature/Humidity Sensors. Add the DHT22 sensors to the GPIO pins on top of the GSM/LTE hat. The temperature/humidity sensors can vary depending on the manufacturer, therefore different symbols are used to express the purpose of each pin. Shown below are the two most basic cases where GND/- are used for grounding, VCC/+ for power supply and DAT/out for data output. The first sensor should be taken and its power pin connected to one of the 5V pins on the top right side of the GPIO pins emerging from the GSM/LTE hat, the ground pin to a pin that is marked with GND and lastly the data pin to D17 (6^{th} pin on the left side of the pins, counting from the top) using the female-to-female jumper wires. This will be the sensor monitoring the temperature/humidity within the IoT case. Follow the same guidelines for the second sensor but connect the data pin to the GPIO

pin marked with D25 located roughly in the middle of the column of GPIO pins on the right. This sensor will be used to measure the temperature/humidity outside the IoT case.

8) Step 8 – Assemble the Smoke Sensor. To assemble the smoke sensor, take the RPi Pico and connect to its micro-USB port the USB-to-Micro USB cable. Then pick up the MQ2 gas sensor and the jumper wires to connect the analogue output (AOUT) pin of the sensor to the GP26_A0 pin of the Pico, the ground pin (GND) to a GND pin on the Pico and lastly the power (VCC) pin to the Pico pin marked with 3V3 (3 volts). Leave the smoke sensor aside to connect it to the RPi after it has been fastened in the IoT case.
9) Step 9 – Add powerbank. Open the IoT case and stick the powerbank on its back where the Velcro is located. Then depending on the powerbank connect the power cable to the USB/USB type C port and place the spare GPS cable next to it, to keep it out of the way. Make sure to pass the cable from the hole in the back side of the case so that the GPS antenna stays on the outside, because it needs to face the sky to properly work.
10) Step 10 – Mount RPi in Case. Take the placeholder with the RPi and screw it in the IoT case using the M4x20mm screws and a Philips screwdriver. Make sure the SMA antenna mounts are located towards the bottom of the case.
11) Step 11 – Mount Camera in Case. After securing the RPi in the back side of the case, you can now fasten the camera to the lid of the case using the M3x10mm screws and the flathead screwdriver. Adding the two screws diagonally should be sufficient to keep the camera in place.
12) Step 12 – External Cables/Sensors. Since the RPi and camera are in place, you can now mount the GPS antenna in the remaining SMA pin (left side). Simultaneously, take the unmounted (male) end of the antenna cable and push it out through the hole in the back side of the case. Do the same with the DHT22 sensor that has its data pin connected to D25. Therefore, you should have three components sticking out from the back: the male side of the antenna cable, the GPS antenna and finally one of the temperature/humidity sensors.
13) Step 13 – Mount Antenna Cable. To secure the other end of the antenna cable to the outside of the case unbolt the first two (nut and O-ring) metal pieces from the female pin and push the pin through the right top hole of the antenna placeholder (black plastic on the top backside of the case). After that, screw back the O-ring and nut, so that the antenna will not move.
14) Step 14 – Mount Antenna and GPS. Since the antenna pin is secured, you can now add the LTE antenna to it. At the same time, push the GPS antenna cable through the gap in the middle of the antenna placeholder and put the GPS antenna in the square opening at the top. In the square opening there is a magnet so if you placed the GPS antenna correctly it should not move.

15) Connect Smoke Sensor. Take the smoke sensor that you had set aside and push the MQ-2 gas sensor out from the hole in the back. Leave the RPi Pico and cable inside the case, placing them under the USB cable that connects the GSM/LTE hat and RPi. Lastly, plug the USB cable into the top USB 2.0 port on the RPi.
16) Step 16 – Connect RPi to Monitor and Power Up. The last thing to do before powering up the RPi is to connect the Micro HDMI to the RPi and the HDMI to a monitor. After you have connected the RPi to a monitor you can use the power cable, which is connected to the powerbank, to power up the RPi. Within seconds of connecting the power cable to the RPi you should hear the fan working, if not then check that the power cable is pushed in all the way or that the powerbank is sufficiently charged. Otherwise, remove the power cable and reconnect it to reboot the RPi. As a last resort use the power cable and connect it to a USB plug to check if the RPi is booting, if yes then replace the powerbank, otherwise the issue might be with the RPi.
17) Step 17 – Mount IoT Case. To conclude the setting up of the IoT device, you need to take the tree mounting strap and pass it through the hoops in the back. After that you can mount the IoT device to a tree or pole located in the area you wish to monitor.

Figure 9 presents result of the preparation procedure.

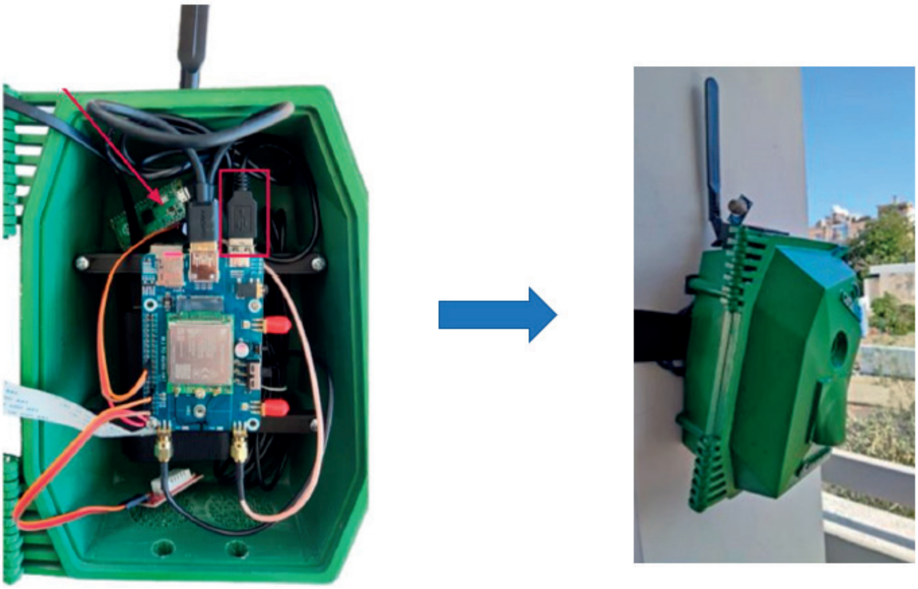

Figure 9. Visualisation of the result of preparation of an IoT device for fire detection
Source: (Catalink, 2024)

Furthermore, operational activities are to a large extent technology-determined. They require connecting to computational device (for example a PC with a monitor) and support from technical staff. Particular steps on how to use IoT device for fire detection are enumerated below (Catalink, 2024):

1) Step 1 – Power Up RPi. So far you should have the IoT plugged to the power bank and connected to a monitor showing on the screen.
2) Step 2 – Open Terminal. At the bottom (or top) of the screen you will see the tool bar where a black square is located (after the folder icon), press it to open up a terminal window.
3) Step 3 – Navigate to Scripts. In the terminal window enter the chosen code lines to navigate to the directory where the scripts are located and activate the environment needed to run them.
4) Step 4 – Connect to Wi-Fi (Optional). By default, the RPi is setup to use mobile data to get access to internet and send data to SILVANUS framework. If Wi-Fi is available, it can be set to use that instead. To do so, click on the arrows on the right side of the tool bar (located at the top/bottom of the screen) to turn-on Wi-Fi and then select the network you wish to connect to.
5) Step 5 – Check VPN Connection. Before testing the different components of the IoT device and running the final script that operates the device, you need to check that it is connected to SILVANUS VPN. If the device is not connected to the SILVANUS network, it will not be able to communicate with the SILVANUS framework, thus no updates from the device will be received/shown in the UI.
6) Step 6 – Check Internet Connection. After checking the connection to the VPN network, check that you have access to the internet, otherwise data will not be sent to the framework. To check the connectivity, enter the system command in a terminal window. If you get a response like the one below, this means you have access to internet and can close the terminal window. Otherwise, check Wi-Fi connection or switch-off the GSM/LTE hat to check if it affects the connectivity. If it is the latter, it is an indication the SIM card is low on money/megabytes, therefore you need to add credit. If the previous actions do not help resolve the issue, try restarting the RPi.
7) Step 7 – RPi Subcomponent Check. To test the different components of the IoT device run the following items: check camera, check sensors, check communication with SILVANUS Framework.
8) Step 8 – Run Fire/Smoke Detection Script. After you have checked that you are connected to SILVANUS VPN and that the subcomponents of the IoT device are working you can run the script that operates them all together. You will see different details of the script's execution being printed on the screen, such as if the SIM hat operates as expected, when an image was captured, sensor readings and finally if the data were successfully sent to

SILVANUS framework. If the execution is successful, you can remove the HDMI cable, close the IoT case and leave it running until the power bank runs out of energy. When the power bank runs out of power you can replace it and rerun Steps 7 and 8 to start the detection of flame/smoke again.

Figure 10 visualises result of the device running.

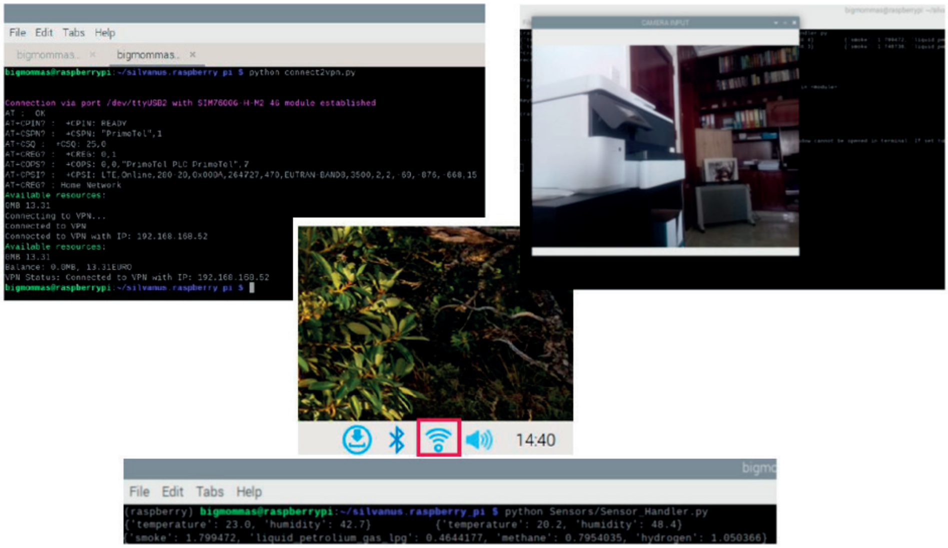

Figure 10. Visualisation of the result of a running protocol for IoT device to detect a fire
Source: (Catalink, 2024)

The last two figures proved the strictly technological character of the preparation and operational use of IoT devices to detect a fire. This is why organisation of the firefighter training should ensure support of technological staff and/or deploy pre-recorded detection data. In addition, the device is not operational-independent. Measurement results should be visualised and/or transmitted to operational centre. In other case the risk of the measurement misunderstanding is unacceptable and fire detection using IoT devise may not play its training role.

2.1.3. Enhancement capabilities

Synergy is noticeable between training for firefighters and fire detection using IoT devices. At the highest level of generality, the training may provide inspirations and evaluation to technology providers, and the provider can expand their offer with IoT solutions that are much better suited to user requirements. This allows mutual enhancement capabilities.

As far as training-related preparation and pre-planning activities for wildfire response are concerned, the application of fire detection using IoT devices allows achieving enhancement by:

a) shortening the time between ignition of a wildfire and its identification,
b) making warning activities immediate,
c) shaping operational picture related to a wildfire,
d) automating fire detection processes,
e) widening area covered by fire monitoring,
f) basing on real case studies.

General training improvements stem from automation processes generated by IoT devices. They allow saving resources not only before and during training but also in real operational circumstances. It is noticeable especially in the case of operational staff. The necessity of connecting IoT devices with some kind of visualisation and/or computational equipment is considered a chance to integrate this technology to other detection solutions and to commonly visualise the detection results. This may reduce risk related to false positives and make detection information more reliable.

As regards fire detection using IoT devices, their deploying in preparation and pre-planning activities for wildfire response (with particular attention to specific training activities) may inspire seeking technology improvements by:

a) new kinds of data sensed and reported,
b) new reporting mechanisms,
c) integrating with other detection solutions,
d) visualisation in GIS tools,
e) designing user-oriented solutions,
f) implementation of machine learning and interoperability with other detection tools to reduce false positives,
g) designing a dashboard and other visualisation tools as regards intuitive use by firefighters.

These lines of improvement justify the need to improve IoT devices in close conjunction with user needs and other solutions that address preparation and pre-planning activities for wildfire response. Proceeding in this way ensures that end-users (for example firefighters) receive solutions tailored to their needs while technology providers will match real operational expectations and generate the synergy effect between multiple technologies.

As far as enhancement capabilities are concerned, they are noticeable both for training and considering the devices. The following aspects should be considered:

1) as regards training-related preparation and pre-planning activities for wildfire response:
   a) mass scale of the incident and consequently many devices to be deployed,
   b) strong dependence on technical staff support;

2) as regards fire detection using IoT devices:
   a) stress related to using a tool,
   b) the inability of trainees to use the equipment themselves ,
   c) stress related to the use of technology,
   d) uncertainty related to data,
   e) stress-tests for the devices may be destructive to them.

Practical limits for the enhancements stem from technology specifics of the solutions. However, the training practice comprises organisational solutions that may be implemented to conduct training regardless of the caps and with positive impact on preparation and pre-planning activities for wildfire response.

2.1.4. Safety issues for the deployment of the technology

When deploying technologies for fire detection using IoT devices into preparation and pre-planning activities for wildfire response it is necessary to take into account safety issues. It is reasonable also from the perspective of a training course. The following factors need to be highlighted (Rączkowski, 2022):

1) Hazards associated with moving, loose and protruding parts.
2) Fall from a height.
3) Electrical shock.
4) Fire-related hazards (thermal radiation, smoke).
5) Biological factors.
6) Mental burden.

Table 2 contains information that expresses examples of the hazard materialisation circumstances.

Table 2. Illustrative circumstances of hazard materialisation when using fire detection based on social sensing to train firefighters

No.	Hazard	Illustrative circumstances
1	Hazards associated with moving and loose and protruding parts	a) Being hit by a screen. b) Being hit by RPi. c) Being hit by environmental element (for example by a branch). d) Tripping over a land unevenness in the woods. e) Stumbling over a computer post. f) Tripping over a cable.
2	Fall from a height	a) Fall from a height (for example from a tree) while installing/servicing RPi.
3	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to the training infrastructure (a light fixture, an electrical socket).

No.	Hazard	Illustrative circumstances
4	Fire-related hazards (thermal radiation, smoke)	a) Thermal radiation from a fire while operating in danger zone. b) Smoke contamination while operating in danger zone.
5	Biological factors	a) Biological agents transmitted by other trainees (air ways). b) Biological agents accumulated on training infrastructure and devices. c) Dangerous animals in the woods.
6	Mental burden	a) Situational stress. b) Inabilities to use the assessment tool. c) Technical problems with IoT devices and relevant software.

Source: own study

The following prevention measures are suggested to reduce training risks related to the enumerated hazards:

1) for hazards associated with moving and loose, sharp and protruding parts:
   a) to fix firmly the screens and cables (for example to walls),
   b) to fix firmly IoT devices (for example to trees, walls),
   c) to mark safety distances (at least 1 m) around the training platform and other training areas,
   d) to ensure order in the training zone;
2) for fall from a height:
   a) to use mountaineering equipment when deploying IoT devices on the field,
   b) the performance of all maintenance and servicing operations by at least two technicians;
3) for electrical shock:
   a) to check electrical devices before every training session,
   b) to work out a safety procedure to respond to any physical damage in equipment and infrastructure;
4) for fire-related hazards (thermal radiation, smoke):
   a) to remain in contact with training organisers who know where the fire has occurred,
   b) to keep clear of fire (flames, smoke),
   c) to ensure and secure an evacuation route and an alternative evacuation road;
5) for biological agents:
   a) to disinfect training area after every scenario,

   b) to disinfect equipment after use,
   c) to work out a biological safety manual,
   d) to verify the health status of each trainee,
   e) to ensure a technical worker to selectively use the computer post with a dashboard;
6) for mental burden:
   a) to ensure a friendly atmosphere during a training course,
   b) to provide support of members of the technical staff to the trainees in the technical use of the tool,
   c) to organise a training course with a scenario that is relatively independent on the detection effectiveness (in case of low effectiveness of the use or technical problems with fire detection using IoT devices).

As preparation and direct use of IoT devices for fire detection are generally dedicated to technology providers, the work risk is higher for technical staff members than for firefighters. For firefighters the training specifics corresponds to office work. A different situation is observed for technology providers who may conduct their activities in field conditions. This highlights the necessity of ensuring safety not only for trainees but also for technical staff members.

2.2. Fire detection at the Edge

2.2.1. Technology in a nutshell

"Artificial intelligence, or AI, is technology that enables computers and machines to simulate human intelligence and problem-solving capabilities" (IBM, 2024). It is primarily based on software tools. The tools facilitate the use of multiple computational solutions to solve complex qualitative and/or quantitative problems. The specific aspect of AI practical use is that the technology is required to learn before it suggests a solution to a problem. This is related to the need of providing access to data (which is not often accessible, reliable, complete, etc.). However, the development of IoT devices and the so-called 'smart solutions' (smart city, smart transport, smart production, smart delivery, smart safety, smart security) allows thinking positively of data resources that seem to be everywhere around a human being (Lacinak, Ristvej, 2017; Ristvej at al., 2020). In addition, potential benefits associated with AI are highly valuable. Therefore, this technology has found its way into disaster management theory and practice in recent years. This also applies to wildfire response. As an example, AI is used for identifying and analysing natural disasters from the social media (Sufi, 2022). It provides support in locating and deploying essential goods and equipment in disasters (Farazmehr, Wu, 2023). The technology is also helpful for early warning purposes (Liu et al., 2023).

The specific deployment of AI in wildfire response is fire detection at the Edge. It means hazard detection capabilities built on the integration of analytical (computer vision) algorithms with data from IoT devices as well as photos and movies collected from the ground (robots) and from the air (drones). The integration ensures data flows from detectors to the algorithms. This can be achieved with the use of MESH-in-the-Sky (see section 4.4.) or by direct downloading from the edge devices (for instance from smoke detectors after arrival on the wildfire scene). Fire detection at the Edge focuses on identification, verification and confirmation of occurrence of wildfire manifestations, namely flames and a smoke. Detection results may be geo-localised and shared among multiple stakeholders via IT dashboard (see section 6.3) (SILVANUS, 2024). This reflects broad possibilities of integrating AI to other technologies that are useful for wildfire response. As regards other examples, it is worth mentioning AI-powered drones and the IoT (Ramadan et al., 2024).

Taking into consideration potential technology beneficiaries, every entity that analyses video data or sensor data for the purposes of wildfire detection may be interested in fire detection at the Edge. These could be analytical units of forest services, action staff members of fire services, emergency management centres, disaster management centres, and crisis management centres. As information about hotspots can be sent also to line responders, it could be helpful for line commanders and line firefighters to adjust firefighting tactics and to ensure their personal safety in wildfire conditions. The core of the technology is the software solution. This is why fire detection at the Edge may be implemented to training of wildfire responders (for example after uploading pre-defined or pre-collected data).

The main functionality of fire detection at the Edge is to analyse video data and sensor data to confirm a fire breakout in the woods. The algorithms are designed to verify flames and smoke. Respecting the technology specifics, the following capabilities and benefits are reported (SILVANUS, 2024):

1) autonomous fire detection resulting from verification of the occurrence of flames,
2) autonomous fire detection resulting from verification of smoke occurrence,
3) detection of fire and smoke in real time footage,
4) uploading from any available source capable of providing a video or an image (cameras),
5) uploading by IoT devices,
6) functional integration to drones and robots,
7) functional integration to MESH-in-the-Sky,
8) functional integration to geospatial information systems (GIS),
9) automation of the fire detection process,
10) monitoring fire development,
11) uploading to the decision support systems,
12) liberating operator from monotonous tasks,

13) visualisation of hotspots and smoke-determined danger zones.

Figure 11 presents results of a visualisation of a danger zone (smoke) and hotspots after the use of fire detection at the Edge (view from a drone).

Figure 11. Visualisation of danger zone (smoke) and hotspots using fire detection at the Edge (view from a drone)

Source: (SILVANUS, 2024)

The tool is not independent from the implementation point of view. It requires integration to hardware solutions (for example a drone and a computer in an emergency management centre or a forward command centre). This highlights its intermediary role between sources of information and decision-making processes. On the other hand, it should be emphasized that the real potential of fire detection at the Edge relies significantly on the sources and the processes.

Fire detection at the Edge is implementable to wildfire response when proper data is available. As the data can be pre-defined and/or pre-collected, the solution may be used in training for firefighters. Confirmed information about a danger zone and hotspots is important to make first response decisions, including dispatching qualitatively and quantitatively adequate resources of responders as well as location and distribution of the action scene. It helps to form a first view of the situation.

2.2.2. Operational protocol of the technology use

Edge fire detection is attributed to a universal process of wildfire response. Relations connecting the technology and the process may be described by implementing the operational protocol. The relations are presented on Figure 12. They determine the technology use in training for firefighters.

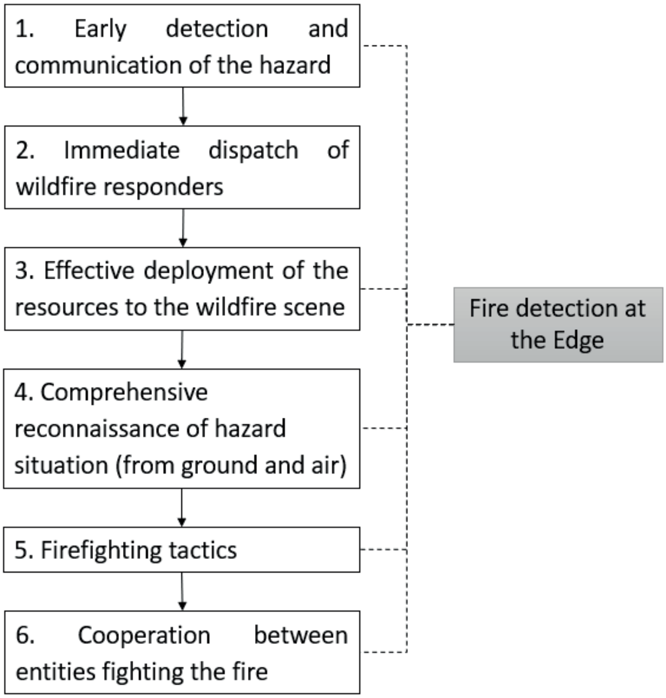

Figure 12. Application of fire detection using IoT devices in support of wildfire response training

Source: own study

The technology is implementable to training processes for all phases of wildfire response. They are early detection and communication of the hazard, immediate disposal of wildfire responders, effective provision of resources to the wildfire scene, comprehensive reconnaissance of hazard situation (from the ground and from the air), firefighting tactics and cooperation between firefighting entities. Information about the specific location of a hazard is of great importance for conducting firefighting activities in these phases. Fire detection at the Edge is valuable from this viewpoint because it allows reporting not only the fact of an occurrence of a hazard but also its geospatial coordinates (for instance after integration with GPS technology). All these issues may be reflected in training for firefighters. Table 3 shows examples on how to implement fire detection at the Edge into training activities with respect to particular response phases. It is a kind of operationalisation for operational protocol of the technology use for the purposes of training for firefighters.

Table 3. Examples on how to implement fire detection at the Edge into particular phases of wildfire response

No.	Phase	Examples
1	1. Early detection and communication of the hazard	1) Trainee identifies system alert on hazard detection (smoke). 2) Trainee identifies system alert on hazard detection (flames). 3) Trainee verifies reliability of information concerning the fact of hazard occurrence.
2	2. Immediate dispatch of wildfire responders	1) Trainee analyses the hazard situation to dispatch wildfire resources that are quantitatively and qualitatively adequate to situational picture. 2) Trainee indicates wildfire resources to be sent to the action.
3	3. Effective deployment of resources to the wildfire scene	1) Trainee adjusts arrival route to the wildfire scene with regard to the location of hotspots and smoke. 2) Trainee seeks alternative directions and arrival routes in case of wildfire develops that is reflected by location of hotspots and smoke.
4	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee analyses sensor readings, pictures and movies collected by the Edge tools to verify situational picture and analyse its development. 2) Trainee verifies accessible sources of information and indicates firefighters to check their correctness.
5	5. Firefighting tactics	1) Trainee monitors the range of the danger zone (smoke) for planning of firefighting tactics. 2) Trainee monitors location and number of hotspots for planning of firefighting tactics.
6	Cooperation between firefighting entities	1) Trainee shares information about the range of the danger zone (smoke), and location and number of hotspots among other co-operators (for example forest service and public administration).

Source: own study

The use of fire detection at the Edge in wildfire response training requires following general operational activities with respect to the integrated technologies. The activities are as follows:

1) Physical integration of the technology to other technologies (for example drones, robots, IoT devices).
2) Functional integration of the technology to other technologies (for example sensor readings, generating pictures and/or movies, transferring data).
3) Familiarisation with the training scenario.
4) Instruction for the proper use of fire detection at the Edge or getting support from a trainer (the tool operator).
5) Pre-training use of fire detection at the Edge on the semi-scenario (elements of training scenario) to find out kinds of information that may be obtained with the use of the tool.
6) Essential use of fire detection at the Edge to implement the training scenario (directly by a trainee or indirectly with the support of a trainer).
7) Debriefing after the training and training evaluation.

In general, the use of fire detection at the Edge during training for firefighters does not require any specific efforts or resources. It is justified by the specifics of this technology. However, the case is quite different when additional tools and solutions are integrated and commonly used. On the one hand, support of relevant technology providers is desirable then. On the other hand, complex scenarios can be implemented and firefighters may be devised more comprehensively to wildfire response.

2.2.3. Enhancement capabilities

The use of fire detection at the Edge in training for firefighters can generate two kinds of organisational benefits. The first one comprises advantages for firefighters and other wildfire responders. The second one concerns benefits for technology providers to inspire them in developing the technology in ways important for end-users and taking their expectations into regard. This may generate the synergy effect that shortens the distance between operational needs and technology functionalities as regards such an essential issue as localisation of a hazard.

As far as training-related preparation and pre-planning activities for wildfire response are concerned, the application of fire detection at the Edge allows achieving considerable enhancement by:

a) shortening the time between materialisation of wildfire manifestations (flames and smoke) and confirmation of the hazard occurrence,
b) automating fire monitoring,
c) widening the area comprised by fire monitoring,
d) adjusting the area comprised by fire monitoring to current operational needs (for example by using drones or robots),
e) reducing the risk of false positives in the fire detection process,
f) take immediate warning action,

g) shaping the operational picture related to a wildfire,
h) basing on real data,
i) possibility of covering a wide spectrum of fire scenarios,
j) learning AI algorithms to identify derivative threats of a wildfire (for example when critical infrastructure is placed in danger zone).

Improvement opportunities related to the benefits for firefighters and other fire responders are derived from increased immediacy of response through faster detection of the hazard. Moreover, fire detection at the Edge allows enhancing operational flexibility by deploying additional sensors and other information sources (for instance a camera on a drone) in different places. This may be done not only in the preliminarily defined danger zone but also outside it, or on the borderline, to make the situational picture complete. As the next benefit, AI technology reduces risk of false positives so end-users may be sure that a hazard really exists, and the decision-making process is carried out rationally and on the basis of real premises.

As far as the technological viewpoint is concerned, implementation of fire detection at the Edge to preparation and pre-planning activities for wildfire response (placing special attention on training for firefighters) may inspire seeking of further improvements by:

a) new kinds of edge solutions integrated,
b) new kinds of sensor data used,
c) more effective learning algorithms,
d) new solutions for effective AI training,
e) new ways to visualise analysis results,
f) connection to GIS visualisation and analytical tools (for example network analyst),
g) designing user-friendly solutions,
h) focusing on in-depth reduction of false positives,
i) designing a dashboard and other visualisation tools related to intuitive use by firefighters.

It is hard to expect that technology providers could guess operational needs of firefighters. It is also hard to imagine that firefighters implement AI solutions (including fire detection at the Edge) that do not reflect their needs. Consequently, the rational way for any improvements is to involve these two groups of stakeholders to make common efforts and elaborate tailor-made tools. It seems to be especially important when considering AI. The technology may be perceived as very hard to understand by users who are not IT specialists.

The above-mentioned issues highlight that the use of fire detection at the Edge and other AI tools may be affected by operational risks related to implementation and deployment in wildfire response. This means enhancement caps that can be reported in both improvement concepts. Thus, the following aspects should be taken into consideration:

1) as regards training-related preparation and pre-planning activities for wildfire response:
   a) mass scale of the incident and consequently a number of data sources to integrate,
   b) strong dependence on technical staff support,
   c) responsibility that still rests with the line commander and limits the exploitation of AI,
   d) relatively low trust in AI (in general),
   e) necessity to train AI algorithms before putting them into practice,
   f) AI determination by data (visual data, sensor data, etc.);
2) as regards fire detection at the Edge:
   a) stress related to the use of a tool,
   b) the inability of trainees to use the equipment themselves,
   c) stress related to the use of technology,
   d) uncertainty of data that feed algorithms,
   e) misunderstandings related to algorithms,
   f) stress-tests for sources of data may be destructive to them.

Practical limitations of improvements concern technology specifics of the solutions, determination by data, and common perception of AI technology. Nevertheless, AI has been developing for last years and its development seems to be shaping the current understanding of new technologies and modern technologies. Training processes can help address these issues and facilitate synergies between end-users and technology providers.

2.2.4. Safety issues for the deployment of technology

Training for firefighters needs to reflect operational challenges associated with wildfire response. However, training conditions should ensure personal safety for trainees. This specific dissonance can be addressed by focusing on and respecting the following factors (Rączkowski, 2022):

1) Hazards associated with the movement of people.
2) Electrical shock.
3) Visual radiation.
4) Biological factors.
5) Mental burden.

Table 4 contains information that presents examples of the hazard' materialisation circumstances.

Table 4. Examples of circumstances in which hazards materialise when using fire detection at the Edge to train firefighters

No.	Hazard	Illustrative circumstances
1	Hazards of moving, loose and protruding parts	a) Being hit by a screen. b) Stumbling on a computer post. c) Tripping over a cable.
2	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to the sensing equipment. c) Physical damage to the training infrastructure (a light fixture, an electrical socket).
3	Visual radiation	a) Radiation generated by screens.
4	Biological factors	a) Biological agents transmitted by other trainees (airways). b) Biological agents accumulated on training infrastructure.
5	Mental burden	a) Misunderstanding of algorithms. b) Situational stress. c) Stressful competition. d) Too many sources of information (information overload). e) Cognitive inability to use the tool.

Source: own study

Following prevention measures are suggested to reduce training risks related to the hazards enumerated:

1) for hazards of moving, loose, sharp and protruding parts:
   a) to fix firmly screens and cables (for example to walls),
   b) to set out safety distances (at least 1 m) around the training platform and other training areas,
   c) to ensure order in the training zone;
2) for electrical shock:
   a) to check electrical devices before every training,
   b) to work out safety procedures to respond on any physical damage in equipment and infrastructure,
   c) to involve technical staff support when using specialised data sources,
   d) to use pre-recorded and/or pre-collected data to feed algorithms;
3) for visual radiation:
   a) to ensure proper illumination in the training room;
4) for biological agents:
   a) to disinfect the training area after every scenario,
   b) to disinfect equipment after its use,
   c) to work out a biological safety manual,
   d) to verify the health condition of each trainee;

   e) to ensure a trainer to selectively use the computer post with a dashboard;
5) for mental burden:
   a) to minimise or eliminate competition elements from the training scenario,
   b) to ensure a friendly atmosphere during a training course,
   c) to ensure that staff members support trainees in the technical use of the assessment tool (including support in proper interpretations of assessment results),
   d) to organise a training course with a scenario that is relatively independent of the detection effectiveness,
   e) to work out a short manual describing practical ways of fire reduction at the Edge.

Safety measures dedicated to firefighter training with the use of fire detection at the Edge entail office work. This is noticeable when the training curriculum does not consider any additional equipment, tools, sensors, drones, robots, etc. The situation is typically different in the case of field conditions. Additional safety measures may prove to be required to ensure personal safety for firefighters affected by hazardous factors, physical factors, chemical factors, biological factors, psychophysical factors and social factors. Even if the analysed technology is not challenging from this point of view, it might be when integrate it with other technologies.

2.3. Fire detection based on social sensing

2.3.1. Technology in a nutshell

Fire detection initiates an entire process of wildfire response. Bystanders and witnesses are very often the first ones to notice a hazard. The shorter the time between hazard identification and warning of public services, the greater the chance of immediate response and putting out the fire with minimal losses. In the approach of social sensing, everyone may play a role of "a human sensor". The idea is to ensure that a warning message can be sent as quickly as possible to those responsible for safety (firefighters, forestry services, emergency management centre, etc.). Consequently, the society could be understood as the detection network for hazards.

A significant role in social sensing is played by social media and relevant tools (Aggarwal, Abdelzaher, 2012). The development of social media leverages new possibilities to monitor hazards and inform about their occurrence. This is especially noticeable nowadays, in the age of social sensing – a time when a substantial amount of people has access to social media and multiple ways of communication.

In line with the specificity of social detection, it can support beneficiary entities such as fire centres, forest centres, emergency management centres, disaster management centres, crisis management centres, field commanders and citizens in hazard area. The compiled information may be useful not only for fire detection but also to monitor the range of the danger zone (on the basis of changes in places where the fire is noticed). Two operational risks should be highlighted in this context. The first one is the difficulty in marking the specific location of the hazard from the ground perspective (the perspective of a person who saw and/or sensed the fire). The second one is risk related to deliberate behaviour expressed by providing fake news or execution of sabotage operations (for example to unnecessarily focus attention of firefighters on some area). However, these risks may be reduced through close cooperation with firefighters. Consequently, social sensing should be included in training processes aimed at fire detection.

The main functionality of social sensing in fire detection is to indicate at least an approximate location of the hazard as regards analysing social media content (pictures, photos, tweets, posts, messages, etc.). Exemplary package of information feeding the social sensing tool is presented on Figure 13.

Figure 13. Sample public post uploaded by a member of the city council for the Municipality of Nové Mesto, Bratislava

Source: (SILVANUS D4.2, 2023)

As far as specific functionalities are concerned, social sensing allows strengthening fire detection by (SILVANUS, 2024):

1) shaping situational awareness,
2) real-time monitoring,
3) prompt responding,
4) raising public awareness and communication.

Shaping the situational awareness is essential for safety when a hazard materialises. Information about the hazard zone and intensity facilitates making informed decisions. Real-time monitoring means continuous analysing of the social media content to immediately identify information proving that a fire has indeed occurred (for example via posts, tweets, photos, messages). Prompt response is related to urgent dispatch (as soon as possible) of firefighters to action. Social sensing may provide guidelines on the amount of resources to be involved in the action and where they need to be deployed. The last aspect concerns raising public awareness and communication. Social sensing tools may help citizens and safety entities to monitor the status of emergency/disaster situation. Creation of a common operational picture and knowledge is crucial to form a background for rational behavioural patterns and to ensure cooperation potential between rescuers and citizens.

As an example, it Is possible to describe functionalities of the SILVANUS Fire Detection based on Social Sensing tool . A fire may be identified given the following:

a) textual and visual location extraction,
b) fire and smoke detection on images,
c) relevance classification,
d) text categorization,
e) textual and visual concepts extraction,
f) event reconnaissance,
g) fire incident detection.

In detail, the tool executes the collection process of social media posts (from X platform). This means active monitoring of X activities and the crawling of social media posts. The hazard is located thanks to geotagging of compiled information. As the next step, the tool carries out fire event detection through spatiotemporal clustering as well as enhances the precision of wildfire identification. This allows enhancing user experience in the standalone user interface for the visualisation of dangerous events (SILVANUS D4.2, 2023).

Basing on the SILVANUS example, the social media sensing tool requires access to a visualisation solution (for example a kind of a dashboard – a friendly Web interface that illustrates fire events as pop-ups on a map). Integration of social sensing and GIS is highly important from the perspective of practitioners (for example firefighters) and citizens (Athanasis et al., 2015). The integration allows geo-localisation of the hazard and adjusting decisions to real hazard conditions.

Figure 14 shows an example of a dashboard that was devised for wildfire detection as regards social sensing.

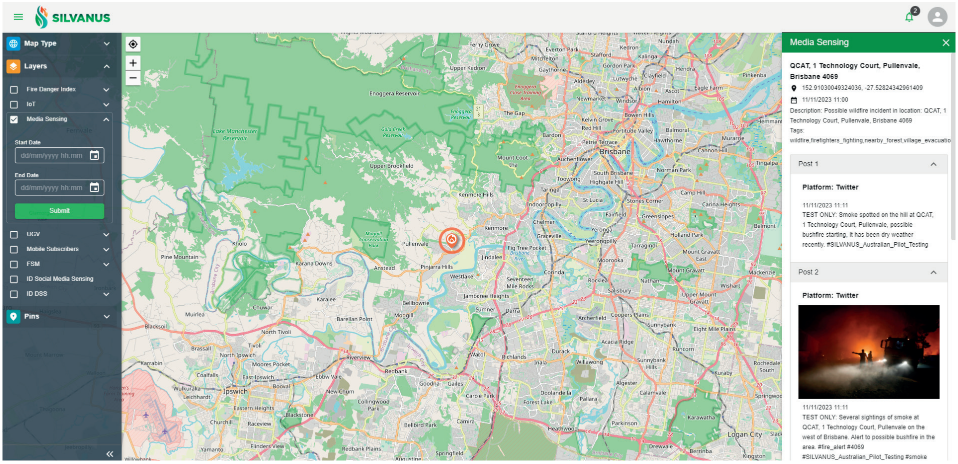

Figure 14. Dashboard used for wildfire detection as regards social sensing in SILVANUS
Source: (SILVANUS D4.2, 2023)

As wildfire response relies on locating the hazard, social sensing may be applied in training for firefighters. The compiled information may be useful to make first decisions as to kinds and number of firefighting resources to be dispatched. This defines an overall qualitative-quantitative view on the amount of resources needed in the response action as well as may determine first tactical assumptions.

2.3.2. Operational protocol

Operational protocol related to the implementation of fire detection based on social sensing in wildfire response training should refer to a universal process of wildfire response. Logical connections between the process elements and relevant detection functionalities are shown in Figure 15.

The technology impact concerns all phases of wildfire response. These are early detection and communication of the hazard, immediate dispatch of wildfire responders, effective deployment of resources to the wildfire scene, comprehensive reconnaissance of hazard situation (from the ground and from the air), firefighting tactics and cooperation between firefighting entities. All of them are time-determined. This is why quick information from citizens about dangerous situations may prove to be so critical. Table 5 compiles examples on how to use Fire Detection based on Social Sensing tool, in particular phases indicated on the figure 15.

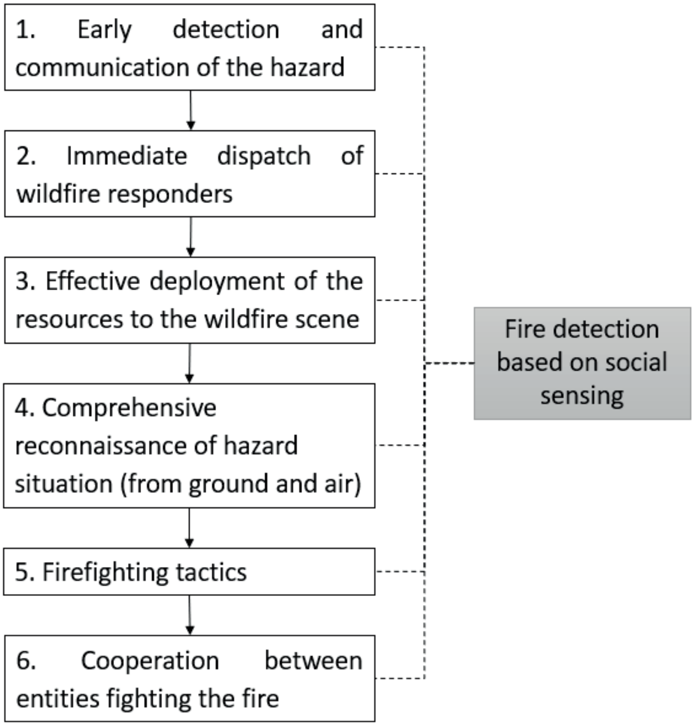

Figure 15. Application of fire detection based on social sensing in support of wildfire response training

Source: own study

Table 5. Examples on how to use fire detection based on social sensing tool in particular phases of wildfire response

No.	Phase	Examples
1	1. Early detection and communication of the hazard	1) Trainee confirms the fact of hazard detection. 2) Trainee verifies the reliability of information concerning the fact of hazard occurrence. 3) Trainee designates the zone where a wildfire occurred.
2	2. Immediate dispatch of wildfire responders	1) Trainee makes first selection of firefighting resources to be deployed to the wildfire scene.
3	3. Effective deployment of resources to the wildfire scene	1) Trainee adjusts arrival route to the wildfire scene considering the location of hotspots. 2) Trainee seeks alternative directions and arrival roads in case the wildfire develops as reflected by location of hotspots.

Table 5 cont.

No.	Phase	Examples
4	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee analyses the wildfire scene from the general air perspective to collect basic reconnaissance information about the location of hotspots.
5	5. Firefighting tactics	1) Trainee marks danger zone for further planning of firefighting tactics.
6	6. Cooperation between firefighting entities	1) Trainee identifies operational needs (for example evacuation, water delivery roads) to be shared among wildfire actors as regards to hotspot location.

Source: own study

Even if the scope of information stemming from the use of Fire Detection based on Social Sensing tool is relatively small, the tool may be deployed in training for firefighters. From the technical viewpoint, three Social Media Crawlers are capable of collecting practically in real time posts based on user-defined keywords and certain accounts from three different social media sources: X platform, Facebook and websites. The posts are processed through a comprehensive Social Media Analysis Toolkit. It utilizes advanced algorithms to extract valuable higher knowledge from the textual and visual content of the posts. The extracted knowledge assists in detecting relevant fire events and gaining a deeper understanding of the potential fire incidents. And lastly, the Fire Event Detection Module monitors the social media posts and produces information about fire events when a significant number of posts related to fires become accumulated within a certain amount of time in specific geographic region (SILVANUS D4.2, 2023). From the practical point of view, there is no need for the trainee to moderate every particular step of this process. It is sufficiently to indicate a time period for analysis and the software will do the rest. Figure 16 shows the tool window to make the time-related assumption and initiate media sensing analysis algorithms. This functionality makes it also possible to compare different time horizons and seek trends in relevant results as regards passage of time.

In the following step the user is navigated to the layer by clicking the corresponding box on the dashboard. This action triggers the activation of media sensing. The user has the option to specify the date time for fire event detection, facilitating filtering events based on their temporal relevance. Figure 17 presents this stage below.

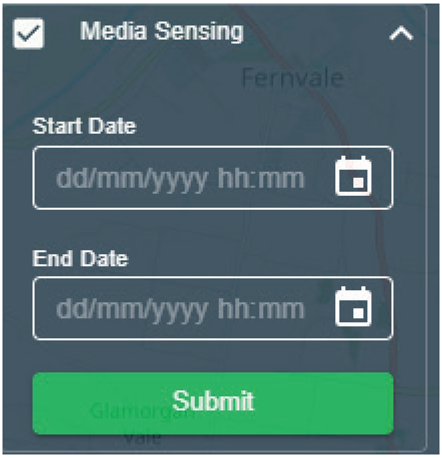

Figure 16. Media sensing activation window
Source: own study

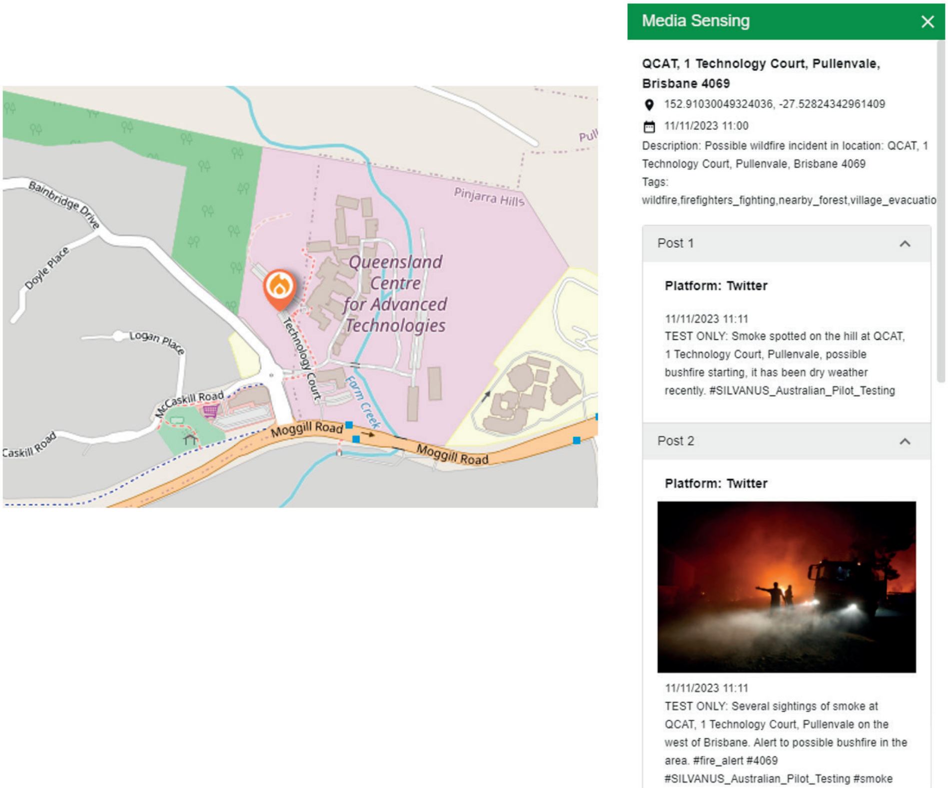

Figure 17. Fire Event Detection Information
Source: own study

Upon clicking the pin, the tool presents detailed information regarding the fire event detection that is the output of a review of social media posts. This includes:

a) Coordinates: Pinpointing the geographical location of the fire event,
b) Tags: information that represents the event content,
c) Description: A brief overview of the detected fire event,
d) Datetime: The timestamp indicating when the event was identified,
e) Location Name: Precise information about the place where the fire event has occurred,
f) Clustered Posts: Clustered posts related to the fire event, including both text and images sourced from the citizens. This provides a holistic view of the community's response and the impact of the event.

Efficiently utilisation of the tool enhances the ability to monitor and respond to fire events with accuracy and timeliness. The tool may help navigate and leverage the features offered by fire detection by social sensing for effective fire event management.

2.3.3. Enhancement capabilities

The course of training may depend on the use of this specific device, while in turn the means of detecting a fire may depend on the operational needs of firefighters Their mutual relation is reflected in enhancement capabilities.

As far as preparation and pre-planning activities for wildfire response are concerned, the application of fire detection based on social sensing allows relevant training-related enhancement by:

a) shortening the time between ignition of a wildfire and its identification,
b) to take immediate warning action,
c) shaping societal security directly by citizens,
d) determining the sense of safety in citizens affected by a wildfire,
e) providing solutions to the citizens to support firefighters and other wildfire responders with information,
f) basing on real case studies.

In general, information about the location of a hazard is crucial for wildfire response. Social sensing facilitates compiling of this information even before official reports are devised and relevant services confirm such an event directly from the location in question. The open question is for the scope of detection information. Hot spot location seems to be insufficient to design the response at an acceptable level of uncertainty and operational risk. This is why social sensing should consider more data, including a state of direct danger to human life, necessity of evacuation, pre-defined level of uncertainty, additional threats, secondary threats, etc.

As regards fire detection based on social sensing tools, their implementation in firefighting training for preparation and pre-planning activities in wildfire response may result in technology enhancement by:

a) new kinds of data sensed and reported,
b) new reporting mechanisms,
c) integration with GIS,
d) designing user-oriented solutions,
e) implementation of machine learning to reduce false positives,
f) using AI for quicker confirmation of hazard occurrence,
g) designing a dashboard or other visualisation tools as regards intuitive use by firefighters.

Also, in this case it is vital that results of fire detection based on social sensing tools are presented to users. This seems to be typical for IT solutions that support firefighting training. Confrontation of technology with firefighters would facilitate to make the tools user-friendly and reduce operational risks related to their handling.

As regards enhancement limitations, they are noticeable mainly in case of the tools. The following aspects should be considered:

a) limited access to data,
b) differences in tool manipulation abilities of trainees,
c) stress related to the use of a tool,
d) relatively high number of information sources to be analysed,
e) uncertainty related to data,
f) risk of generating fake news.

2.3.4. Safety issues for deployment of the technology

Deployment of fire detection based on social sensing involves indirect contact of technology and the trainees. The intermediate element is generally a training post. Participants are able to analyse the detection results typically from a screen. Consequently, the use of fire detection based on social sensing solutions during training is similar to office work. This determines relevant safety issues. As regards a universal catalogue of personal (occupational) hazards, the following factors should be emphasized (Rączkowski, 2022):

1) Hazards associated with the movement of people.
2) Electrical shock.
3) Visual radiation.
4) Biological factors.
5) Mental burden.

Table 6 provides examples of circumstances in which hazards may materialise.

Table 6. Examples of circumstances involving the materialisation of hazards when using Fire Detection based on Social Sensing to train firefighters

No.	Hazard	Illustrative circumstances
1	Hazards of moving and loose protruding parts	a) Being hit by a screen. b) Stumbling on a computer post. c) Tripping over a cable.
2	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to the training infrastructure (a light fixture, an electrical socket).
3	Visual radiation	a) Radiation generated by screens.
4	Biological factors	a) Biological agents transmitted by other trainees (airways). b) Biological agents accumulated on training infrastructure.
5	Mental burden	a) Situational stress. b) Burdening competition. c) Too many sources of information (information overload). d) Inability to use an assessment tool.

Source: own study

The following prevention measures are recommended to reduce training risks related to the specified hazards:

1) for hazards involving moving, loose, sharp and protruding parts:
   a) to firmly fix screens and cables (for example to walls),
   b) to mark safety distances (at least 1 m) around the training platform and other training areas,
   c) to ensure order in the training zone;
2) for electrical shock:
   a) to check electrical devices before every training,
   b) to work out safety procedure to respond to any physical damage in equipment and infrastructure;
3) for visual radiation:
   a) to ensure proper illumination in the training room;
4) for biological agents:
   a) to disinfect the training area after every scenario,
   b) to disinfect equipment after its use,
   c) to devise a biological safety manual,
   d) to check the health state of every training participant,
   e) to ensure that the trainer can selectively use the computer station with a dashboard;

5) for mental burden:
   a) to minimise or eliminate competition elements from the training scenario,
   b) to ensure a friendly atmosphere during a training course,
   c) to ensure staff members support trainees in the technical usage of the assessment tool (including support in proper interpretation of the assessment results),
   d) to organise a training course involving a scenario that is relatively independent of detection effectiveness (in case of poor performance or technical problems with Fire Detection based on Social Sensing).

Safety issues related to fire detection based on social sensing are not challenging from the practical point of view. They are typical for office work. Some of relevant activities may be transferred onto trainers or supporting staff. In addition, the detection results can be pre-defined and delivered to trainees as “ready to interpret”. The last aspect gains in importance when complex computational and analytical solutions are implemented for the detection and sensing purposes.

Chapter 3

Streamlining preparation and pre-planning activities for fire response using reference calculation tools for firefighter training

3.1. Biodiversity profile mobile app (Woode)

3.1.1. Technology in a nutshell

Biodiversity profiling is gaining importance as it addresses the environment in forests in fire conditions. Biodiversity means awareness especially about species of trees and their location. Trees differ as to their combustible properties. The presence of trees characterised by high fire vulnerability and fire load determines the wildfire risk in a given area.

Knowledge of biodiversity is valuable for assessing the risk of wildfires in an area, as well as for feeding fire development forecasting models. Consequently, main beneficiaries of the profiling functionality comprise forest services, firefighters and analytics. In general, they may be divided into entities that collect information about the environment of the woods from the field perspective and entities that use this information to make analyses and wildfire forecasts.

A significant functionality of biodiversity profiling is to identify what kinds of tree species grow in an analysed area. It may be carried out on the basis of photos of leaves. Figure 18 shows the screen from biodiversity profiling application where the leaves are identified and analysed.

There are two specific functionalities of biodiversity profiling tools worth of mentioning in terms of preparation and pre-panning activities for wildfire response. They are:

1) feeding fire risk assessment,
2) providing data for fire spread forecast.

Biodiversity profiling is a kind of functionality. From the operational viewpoint it is not standalone. Its practical use depends on integration with hardware and a visualisation tool. The SILVANUS project implements the functionality of

Figure 18. View of general steps to use Woode
Source: (SILVANUS, 2024)

biodiversity profiling. As an example, the functionality is deployed in the tool called Woode (SILVANUS, 2024). It is a mobile application and may be installed in a smartphone. It facilitates use by forest services and firefighters because, from practical point of view, it is sufficient to just get a mobile device with Woode to the field. Another issue is to integrate it with a visualisation tool. In this case a dashboard is necessary to mark biodiversity profiling results on a map and share it among users.

3.1.2. Operational protocol

Operational protocol related to the use of biodiversity profiling functionality in wildfire response training should refer to a universal process of wildfire response. Figure 19 presents this process. In addition, process elements that may be supported by the significant functionality and the specific functionalities are indicated.

Technology impact is especially noticeable in case of early detection and communication of the hazard, comprehensive reconnaissance of hazard situation (from the ground) and firefighting tactics. Those are wildfire response phases in which information about biodiversity profiles is very important to analyse the operational picture as regards wildfire risk and forecast. Table 7 contains examples on how to use biodiversity profile mobile app in particular phases described.

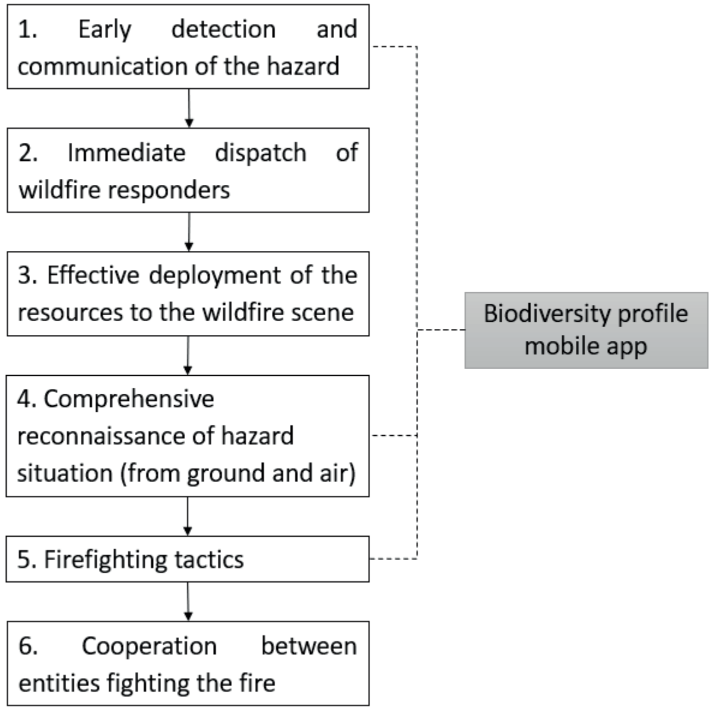

Figure 19. Application of biodiversity profile mobile app in support of wildfire response training

Source: own study

Table 7. Examples on how to use biodiversity profile mobile app in particular phases of wildfire response

No.	Phase	Examples
1	1. Early detection and communication of the hazard	1) Trainee indicates the most probable places where the most serious effects of a wildfire may occur. 2) Trainee analyses the most risky areas in terms of combustible material load.
2	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee analyses the wildfire scene from the general ground perspective to collect basic reconnaissance information about the load of combustible materials. 2) Trainee designates defence lines defined by tree species characterised by low level of vulnerability to a fire. 3) Trainee indicates places to operate UGV connected to UAV in wildfire conditions (near places where high load of combustible materials is noticed).

Table 7 cont.

No.	Phase	Examples
3	5. Firefighting tactics	1) Trainee indicates the most probable direction of the hazard development. 2) Trainee marks areas where special efforts must be undertaken to avoid fire development caused by high fire load (determined by access to huge amount of vulnerable biomass).

Source: own study

The use of a mobile app with a biodiversity profile in fire response training is based on general operational activities. They are as follows:

1) Familiarisation with the training scenario.
2) Instruction for proper use of the biodiversity profile mobile app or asking for support from a trainer (the tool operator).
3) Pre-training use of biodiversity profile mobile app in a semi-scenario (elements of training scenario) to find out kinds of information that may be gained using the tool.
4) Essential use of biodiversity profile mobile app to execute the training scenario (directly by a trainee or indirectly with the support of a trainer).
5) Debriefing after the training and training evaluation.

In accordance with biodiversity profile mobile app specifics, possibilities of operationalizing the operational protocol are quite limited. The protocol should be adjusted to cognitive abilities of trainees as some of them may require support to operate the tool (especially at the beginning of training). Figure 20 shows screens

Figure 20. View of general steps to use Woode
Source: own study based on (SILVANUS, 2024)

from Woode. They seem to be intuitive but also in this case technical support may be needed to lower the stress level among trainees – i.e. stress related to the technology use.

3.1.3. Enhancement capabilities

An operational picture indicates a set of information about a wildfire and its conditions. The picture reflects what firefighters know about the hazard, its intensity, spread, operational chances, secondary threats, etc. It determines the wildfire response. This is why all information that shape the operational picture need to make sure that the response is designed in a rational way. For this reason biodiversity profiling is worth considering when enhancement capabilities are discussed.

Enhancement capabilities are noticeable in both training-related preparation and pre-planning activities for wildfire response and the relevant technology.

As far as training-related preparation and pre-planning activities for wildfire response are concerned, the application of biodiversity profiling allows enhancement by:

a) focusing attention of training participants on areas characterised by the highest risk of fire development,
b) facilitating the establishment of defence lines,
c) using fire development risk as factor determining decisions to be made during a training course,
d) operationalising emergency management and disaster management plans as regards wildfire risk distribution (leveraged by the load of flammable materials),
e) rationalising the location of firefighting resources on the scene in terms of the load of flammable materials,
f) focusing wildfire response efforts on areas with the highest risk of fire development,
g) basing on real case studies.

As a rule, information about biodiversity facilitates assessing wildfire risk and provides additional input to the situational picture. It may affect operational decisions and redeployment of resources.

As far as biodiversity profiling is concerned, its application for training purposes in preparation and pre-planning activities for wildfire response may result in technology enhancement by:

a) inspiring the addition of biodiversity information to fire risk assessment methods,
b) providing new ways of integrating the profiling results to GIS, and to allow their use in geo-spatial analyses,

c) providing new ideas for interpretation of the profiles,
d) designing user-oriented solutions,
e) integrating profiling functionality to mobile tools (for example new smartphones),
f) working out user-friendly dashboard to visualise the profiling results.

In line with its specificity, the solution is a biodiversity profiling function. This assumption is correct when considering a mobile tool for installing the functionality (for example a smartphone). As the functionality is not a standalone solution, strong correspondence with visualisation tools is required. It is related to additional visualisation-related enhancement capabilities.

As regards enhancement limitations, they are noticeable mainly in case of the functionality. The following aspects should be taken into account:

a) different maturity of multiple tools in which the functionality is deployed,
b) limited access to visualisation tools,
c) low level of technology integration with visualisation tools,
d) stress related to the use of a tool,
e) difficulties in proper interpretation of the forecast output,
f) limited access to Internet on wildland areas.

Regardless of limitations, profiling biodiversity seems to be a valuable aspect of gathering information to make situational picture complete. Certain limitations may arise from general technology development. Firefighting training can be used to take this kind of a chance.

3.1.4. Safety issues for deployment of technology

The functionality of biodiversity profiling (for example in the Woode application), for preparation and pre-planning activities for wildfire response, means direct contact of training participants with this technology. As a rule, a training attendee must operate in the field conditions deploying the functionality in practice. This leverages specific hazards. From training safety viewpoint, the following factors should be enumerated (Rączkowski, 2022):

1) Hazards of moving, loose, and protruding parts.
2) Movement of people and equipment.
3) Fall from a height.
4) Electrical shock.
5) Fire-related hazards (thermal radiation, smoke, burn).
6) Microclimate.
7) Severe weather conditions.
8) Noise.
9) Visual radiation.
10) Chemical factors.

11) Biological factors.
12) Mental burden.

Table 8 presents examples of conditions related to hazard materialisation.

Table 8. Illustrative circumstances of the materialisation of hazards/threats when using the functionality of biodiversity profiling in firefighter training

No.	Hazard	Illustrative circumstances
1	Hazards of moving, loose, and protruding parts	a) Being hit by additional equipment. b) Being hit by an environmental element (for example by a branch). c) Tripping on uneven ground in the woods.
2	Movement of people and equipment	a) Being hit by a quad, a fire engine, etc. b) Damage from water drop for fire suppression from the air from an aircraft and/or a helicopter ('Bambi bucket').
3	Fall from a height	a) Fall from a cliff, sinkhole and other terrain unevenness while using a profiling tool.
4	Electrical shock	a) Physical damage to the profiling equipment. b) Physical damage to the training infrastructure (a light fixture, an electrical socket).
5	Fire-related hazards (thermal radiation, smoke)	a) Thermal radiation from a fire while operating in the danger zone. b) Smoke contamination while operating in danger zone.
6	Microclimate	a) Cold microclimate determined by the weather.
7	Severe weather conditions	a) Strong wind. b) High temperature on a sunny day. c) Precipitation (heavy rain, snow, etc.). d) Dense fog.
8	Noise	a) Noise caused by firefighting equipment in field conditions.
9	Visual radiation	a) Solar radiation. b) Radiation from firefighting engines.
10	Chemical factors	a) Chemical substances generated by firefighting engines.
11	Biological factors	a) Biological agents transmitted by other trainees (airways). b) Biological agents accumulated on training infrastructure and devices. c) Dangerous animals in the woods.
12	Mental burden	a) Situational stress. b) Inability of using the profiling tool. c) Technical problems with the profiling tool.

Source: own study

Minimising the occupational risks associated with the use of the biodiversity profiling functionality is possible as regards through the following measures:

1) for hazards related to moving, loose, sharp and protruding parts:
   a) to mark safety distances (at least 1 m) around the training platform and other training areas,
   b) to ascribe the use of the functionality to roles of firefighters that take part in a training,
   c) to ensure order in the training zone,
   d) to ensure protective shoes for trainees;
2) for movement of people and equipment:
   a) to mark walking paths in operational centre,
   b) to ensure order in the training zone,
   c) to ensure visibility of engines and other equipment;
3) for fall from a height:
   a) to mark dangerous places on the training field,
   b) to plan training activities far from dangerous places on the training field;
4) for electrical shock:
   a) to check electrical devices before every training,
   b) to devise safety procedures to respond to any physical damage in equipment and infrastructure;
5) for fire-related hazards (thermal radiation, smoke):
   a) to stay in contact with training organisers who know where fire manifestations had been generated,
   b) to keep a distance from fire manifestations (flames, smoke),
   c) to ensure and secure an evacuation route and an alternative escape road,
   d) to provide personal protection means;
6) for microclimate:
   a) to wear clothes adjusted to weather conditions,
   b) to ensure beverages appropriate for weather conditions (either hot or cold),
7) for severe weather conditions:
   a) to ensure an umbrella and other means of weather protection,
   b) to wear clothes adjusted to weather conditions,
   c) to ensure beverages appropriate for weather conditions (either hot or cold);
8) for noise:
   a) to mark safety distances,
   b) to mark/isolate noisy places (if possible),
   c) to organise places for trainees as far as possible from noisy areas;
9) for visual radiation:
   a) to use personal protection means (for example sunglasses);

10) for chemical factors:
    a) to mark danger zone and ensure safety distances,
    b) to equip personal protection means;
11) for biological agents:
    a) to disinfect the training area after every scenario,
    b) to disinfect equipment after its use,
    c) to devise a biological safety manual,
    d) to verify the health condition of every trainee;
12) for mental burden:
    a) to ensure a friendly atmosphere during the training course,
    b) to ensure technical staff members support trainees in the technical use of the functionality tool to visualise its usage,
    c) to organise a training course with a scenario that is relatively independent of the profiling effectiveness.

A direct use of the biodiversity profiling functionality does not pose significant hazards to attendees in a firefighting training. However, the hazard may be generated due to field conditions of training, and this largely determines the safety of training participants.

3.2. Fire danger risk assessment

3.2.1. Technology in a nutshell

Assessment of wildfire risk is crucial to optimise efforts focused on preparation and pre-planning activities in the analysed context. It gains in importance in the century of disasters when wildfire risk is increasing on a global scale (GAR, 2022). In general, there are not enough resources to fully face challenges related to wildfires as well as to fund and carry out all possible activities to avoid the hazard. Awareness of the risk may facilitate paying special attention to the riskiest areas in the woods. This awareness may be raised further if forest fire behaviour modelling is used (for example empirical models, semi-empirical models, physical models) (Majlingova et al., 2015).

Fire risk may be presented in multiple ways. At the highest level of generality, it is a derivative of a measure of probability of a fire occurring and its consequences (Wolanin, 2020). The following equation reflects this statement;

$$R_w = P_w \cdot C_w$$

where:
R_w – risk of a wildfire,
P_w – probability of a wildfire,
C_w – wildfire consequences.

When a wildfire is understood as a disaster trigger, it may be calculated on the base of following equation (see Sendai, 2015):

$$R_{D\text{-}w} = H \cdot V \cdot E$$

where:
$R_{D\text{-}w}$ – risk of a disaster triggered by a wildfire,
H – measure of a wildfire hazard,
V – vulnerability of a wildfire,
E – exposure to a wildfire.

Many other authors have sought quantitative ways to derive a value for the risk associated with fires. Taking int account the latest scientific works, Ericsson et al. (2023) used for this Fire Weather Index (FWI), the Keetch-Byram Drought Index (KBDI), the Fosberg Fire Weather Index (FFWI), and the Nesterov Index. Chen et al. (2023) focused on the fire danger composite index (FDCI). FDI was calculated on the basis of the Normalised Differential Vegetation Index (NDVI), the Land Surface Temperature (LST), the Temperature Vegetation Dryness Index (TVDI), and forest vegetation types (VT). Erni et al. (2024) connected classical understanding of the risk and the concept of disaster risk reduction. Authors determined the risk by the likelihood (probability of a wildland fire breaking out in a given location), intensity (amount of energy produced by a fire), exposure (spatial coincidence between fire and assets), and susceptibility (prosperity of assets to be affected by fire). McNamee et al. (2022) highlighted that wildfire risk determines and is determined by other co-existing hazards and relevant risk assessment needs to be a kind of multi-risk assessment. In turn Zaidi (2023) has proven that the calculation of wildfire risk is highly complex and requires to be supported by modern computational means (for example by machine learning).

Regardless of the adopted calculation method, wildfire risk depends on the hazard specifics. The SILVANUS project respects this way of thinking and integrates wildfire risk assessment methods with the integrated technological and information platform for wildfire management (SILVANUS, 2024).

Information concerning fire hazard risk assessment results is especially important for analytical teams and decision makers to adjust wildfire management to the level of safety associated with wildfire conditions (the level of safety that is reflected by the level of risk). Public administration bodies, emergency management teams, disaster management teams, crisis management teams and field commanders (from the fire service, the forest service and the armed forces) are primary beneficiaries of fire danger risk assessment. They are obligated to make decisions that respect a number of different hazard conditions and the hazard development forecast. The two may receive information input from the fire danger risk assessment.

The core functionality of fire hazard risk assessment is to provide information concerning the fire hazard risk as a probability for a specific area within a certain forecasting period (for the successive hours, days, months). This is possible owing to "(...) a broad scale assessment of the conditions that reflect the potential, over an area, for a fire to ignite, spread and require suppression action" (SILVANUS, 2024).

The fire hazard risk assessment takes into consideration the following sources of information (SILVANUS D8.3, 2024):

a) weather data (i. e. 2-metre temperature, 10 m wind u component and wind v component, total precipitation and relative humidity),
b) vegetation (Leaf Area Index, Vegetation Index from satellite products (Copernicus Sentinel Products)),
c) land cover (Copernicus data),
d) topography of the area (SAR satellite data or from static land survey maps),
e) historical data about burnt areas.

Consequently, the tool allows obtaining the following (SILVANUS, 2024):

a) hourly weather forecasting for the next 72 hours at a 2km resolution,
b) daily fire weather index predictions based on the Canadian FWI,
c) probabilistic fire weather index for the summer season (JJA) based on CMCC SPS 3.5 and the Canadian FWI,
d) ML inference engine for the next daily fire hazard risk prediction.

From the practical point of view, fire hazard index data are visualised on maps using different colours according to hazard (risk) classes.

Figure 21 presents an exemplary result obtained with the use of fire danger risk assessment.

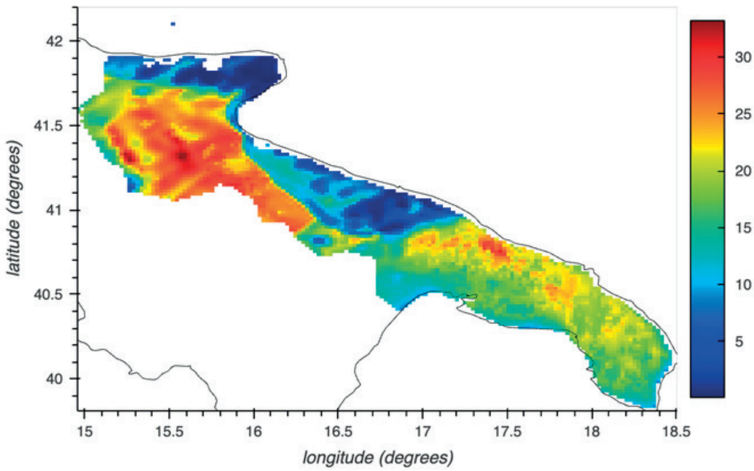

Figure 21. Examples of results obtained with the use of fire hazard risk assessment
Source: (SILVANUS, 2024)

As wildfire management requires access to reliable data, the use of fire hazard risk assessment may prove to be valuable in the optimisation of decision-making processes. It is applicable in all management phases, such as prevention, preparedness, response, as well as reconstruction and recovery. It may be useful when evaluating strategies, operational procedures and cooperation mechanisms. In general, awareness about areas that are characterised by the highest risk is crucial for the rationalisation of common efforts in wildfire management and for facing the cascading effect of hazard development. All these issues may be noticeable in wildfire response training, directly or indirectly.

3.2.2. Operational protocol

Operational protocol related to the use of fire hazard risk assessment in wildfire response training should refer to a universal process of wildfire response. Figure 22 shows the process and indicates process elements that may be supported by relevant assessment tool.

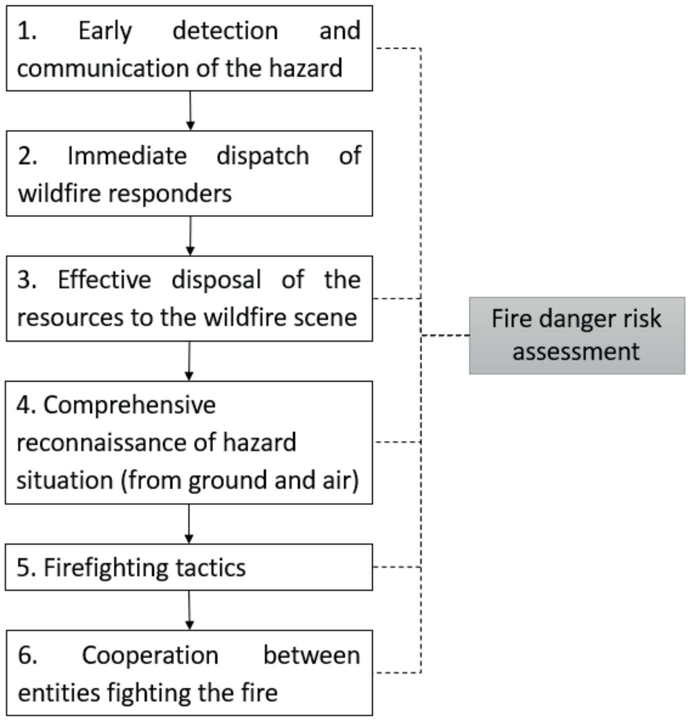

Figure 22. Application of fire hazard risk assessment in support of wildfire response training
Source: own study

The most noticeable technology impact concerns early detection and communication of the hazard, effective deployment of resources to the wildfire scene, comprehensive reconnaissance of hazard situation (from the ground and from the air), firefighting tactics and cooperation between entities involved in firefighting. These are wildfire response phases in which information about the risk is crucial. Table 9 compiles examples on how to use Fire hazard risk assessment tool in particular phases indicated on the figure 22.

Table 9. Examples on how to use the Fire hazard risk assessment tool in particular phases of wildfire response

No.	Phase	Examples
1	1. Early detection and communication of the hazard	1) Trainee indicates the most probable places where a wildfire may occur. 2) Trainee analyses the riskiest areas in a variety of weather conditions.
2	3. Effective deployment of resources to the wildfire scene	1) Trainee adjusts arrival route to the wildfire scene on the basis of wildfire risk. 2) Trainee seeks alternative directions and arrival roads in case of a wildfire that is reflected by relevant risk.
3	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee analyses wildfire scene from the general air perspective to collect basic reconnaissance information about the fire risk. 2) Trainee indicates places to operate UGV in wildfire conditions (as a rule outside the riskiest areas and on the path along which the hazard develops). 3) Trainee indicates places to operate UGV in wildfire conditions (as a rule near the fire flanks).
4	5. Firefighting tactics	1) Trainee indicates the most probable direction of hazard development.
5	6. Cooperation between firefighting entities	1) Trainee indicates a place to gather firefighting resources (outside the riskiest areas of the wildfire scene). 2) Trainee navigates helicopter or plane in accordance with the direction of hazard development to allow making water drop for fire suppression from the air. 3) Trainee communicates with other trainees to exchange operational information related to hazard development.

Source: own compilation

The use of fire hazard risk assessment tool in wildfire response training is based on general operational activities. They are as follows:

1) Familiarisation with the training scenario.
2) Instruction for proper use of fire hazard risk assessment tool or to get support from a trainer (the tool operator).
3) Pre-training use of fire hazard risk assessment tool on the semi-scenario (elements of training scenario) to find out kinds of information that may be obtained with the use of the tool.
4) Essential use of fire hazard risk assessment tool to carry out the training scenario (directly by a trainee or indirectly with the support of a trainer).
5) Debriefing after the training and training evaluation.

In accordance with specifics of the fire hazard risk assessment, possibilities to concretise the operational protocol are quite limited. In addition, the protocol should be adjusted to cognitive abilities of trainees as some of them may require support to operate the tool.

3.2.3. Enhancement capabilities

Training for firefighters provides a valuable opportunity to use the fire hazard risk assessment as attendees are practitioners who work in extremely complex conditions, often involving direct danger to human life. On the one hand, the fire hazard risk assessment may be implemented to operational standards of fire service and other wildfire responders. On the other hand, practitioners' needs, experience and expectations may determine the assessment development.

The use of fire hazard risk assessment tool provides framework for the training. Namely, it allows visualising quasi-real wildfire conditions with additional information concerning high-risk areas and the most probable places where the hazard may materialise.

As far as preparation and pre-planning activities for wildfire response are concerned, the application of the fire hazard risk assessment allows achieving significant enhancement by:

a) focusing the attention of trainees on areas characterised by the highest fire risk,
b) using fire risk as a determinant of decisions to be made during a training course,
c) operationalising emergency management and disaster management plans as regards fire risk,
d) rationalising the location of firefighting resources on the scene in terms of fire risk values,
e) limiting overall wildfire response efforts to areas with the highest risk,

f) analysing fire risk associated with different weather conditions,
g) using real case studies as a basis.

As a rule, wildfire risk facilitates the optimisation of appropriate efforts. It forces on issues and areas that are the most important from the security perspective. In this context resources may be limited to the necessary minimum, the hazard scene can be divided into sub-areas with different operational priorities (for example evacuation), and historic case studies may be analysed and used for the training. This gives a unique opportunity for in-depth collection of lessons learned and to gather them before the hazard materialises.

In accordance with fire hazard risk assessment tools, their application for the purposes of preparation and pre-planning activities for wildfire response may support technology enhancement by:

a) inspiring to work out new calculation mechanisms to obtain information about the risk,
b) integrating these tools with the geospatial information systems (GIS) to easily visualise the risk assessment results,
c) adjusting to operationally-determined sources of information (for example from firefighting statistics and operational risk assessment),
d) formulating new ideas on information on the basis of the assessment,
e) designing user-oriented solutions.

The essential issue is to confront the fire hazard risk assessment tools with the users (firefighters). The confrontation results may give rise to new ideas on what can be done better to reflect real and significant expectations. Firefighters need to make proper decisions very quickly and in a state of uncertainty. Every enhancement to face this set of challenges is promising and worth achieving.

As regards enhancement limitations, they are noticeable primarily in case of the tools. The following aspects should be taken into consideration:

a) limited access to data,
b) differences in tool manipulation abilities of trainees,
c) stress related to the use of a tool,
d) a relatively high number of information sources to be analysed.

These issues determine the training effectiveness and require addressing specific issues that may affect the mental safety of trainees.

3.2.4. Safety issues for the deployment of the technology

Deployment of the fire hazard risk assessment involves semi-direct contact with trainees. This means that training attendee is connected to the wildfire scene with the use of technology (generally via such visualisation equipment as a screen). This determines specific hazards. From training safety viewpoint, the following factors should be highlighted (Rączkowski, 2022):

1) Hazards associated with the movement of people.
2) Electrical shock.
3) Visual radiation.
4) Biological factors.
5) Mental burden.

Table 10 presents examples of circumstances of hazard materialisation.

Table 10. Illustrative circumstances of hazard materialisation when using the fire hazard risk assessment tool in firefighter training

No.	Hazard	Illustrative circumstances
1	Hazards of moving, loose, and protruding parts	a) Being hit by a screen. b) Stumbling over a computer post. c) Tripping over a cable.
2	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to the training infrastructure (a light fixture, an electrical socket).
3	Visual radiation	a) Radiation generated by screens.
4	Biological factors	a) Biological agents transmitted by other trainees (air ways). b) Biological agents accumulated on the training infrastructure.
5	Mental burden	a) Situational stress. b) Burdensome competition. c) Too many sources of information (information overload). d) Inability of using the assessment tool.

Source: own compilation

The following prevention measures are suggested to reduce training risks related to the specified hazards:

1) for hazards related to moving, sharp and protruding parts:
   a) to fix the screens and cables firmly and securely (for example to walls),
   b) to mark safety distances (at least 1 m) around the training platform and other training areas,
   c) to ensure order in the training zone;
2) for electrical shock:
   a) to check electrical devices before every training course,
   b) to devise safety procedures to respond to any physical damage to equipment and infrastructure;

3) for visual radiation:
   a) to ensure proper illumination in the training room;
4) for biological agents:
   a) to disinfect the training area after completing every scenario,
   b) to disinfect equipment after its use,
   c) to work out a biological safety manual,
   d) to verify the health condition of every trainee;
5) for mental burden:
   a) to minimise or eliminate competition elements from the training scenario,
   b) to ensure a friendly atmosphere during the training course,
   c) to ensure staff members to support trainees in the technical usage of the assessment tool (including support in proper interpretation of the assessment results).

Deployment of the fire hazard risk assessment in training for firefighters is associated with a relatively low level of occupational risk. It resembles typically an office job, even if it takes place in field conditions. It comes down to making calculations, visualising them and interpreting their results. It is worth emphasizing that the calculation process is generally automated. Integration to GIS facilitates manual operations and makes them intuitive. This justifies implementing the fire hazard risk assessment tools to GIS solutions and other visualisation platforms where the assessment results are ready to interpret "just after few clicks of a mouse".

3.3. Fire spread forecast

3.3.1. Technology in a nutshell

The fire spread forecast is a crucial functionality in planning wildfire response. It bases on a simulation on how the hazard may develop in the given weather and terrain conditions (Szajewska, 2024). It is cognitively valuable to assess the potential of a fire to cause secondary damages and cover additional ground. It gains in importance especially when the so-called fire weather conditions occur (Wang et al., 2023). The complexity of fire spread forecast forces the deployment of modern computational solutions to indicate a reliable and the most likely direction of the fire movement (Artes et al., 2015; Szajewska, 2024). This is why fire spread forecast processes are supported by network solutions (Khennou, Akhloufi, 2023), machine learning (Michael et al., 2021) and artificial intelligence (Wu et al., 2022). Furthermore, it is also often integrated in sensing technologies (Chowdhury, Hassan, 2015).

The primary beneficiaries of a fire spread forecast are disaster managers and wildfire responders. Managers need adequate, detailed information to get a complete picture of the situation and to make decisions based on likely threat scenarios. Wildfire responders (especially firefighters, forest services and soldiers) should also be informed about the forecast results given the rationalisation of their operational decisions and their personal safety (on-ground activities conducted just before the line of a fire entail an unacceptable risk for the responders). As regards response coherence, both groups of beneficiaries should make use of the same forecast.

The main functionality of the fire spread forecast is to simulate future hazard conditions on the wildfire scene. This requires providing input to computational tools and may comprise such information as (i.a.) (SILVANUS, 2024):

a) terrain elevation,
b) terrain slope,
c) land relief,
d) atmospheric temperature,
e) wind speed,
f) wind direction,
g) fuel type,
h) moisture,
i) canopy characteristics,
j) results of firefighter efforts (for example defence lines),
k) demineralised belts,
l) roads,
m) water reservoirs,
n) bodies of water,
o) current location of the fire front.

Figure 23 and Figure 24 show exemplary results of the forecast taking into consideration different wind fluctuations and multiple wildfire sources.

On the basis of the presented fire spread forecast results, the following specific functionalities may be highlighted:

a) to show the potential range of the danger zone,
b) to show areas characterised by the highest risk of fire development (for example to exclude them from ground operation by firefighters),
c) to simulate potential changes in wildfire development as regards changes in weather conditions,
d) to check how two or more wildfires may co-fuel and aggregate,
e) to find out where the most effective places to build defence lines are located,
f) to indicate evacuation directions,
g) to analyse the worst scenario for a wildfire.

Given the fire spread forecast specifics, it is necessary to emphasize that the forecast is not a standalone solution but rather a kind of functionality. It is of an intangible character and its practical deployment requires using a visualisation tool.

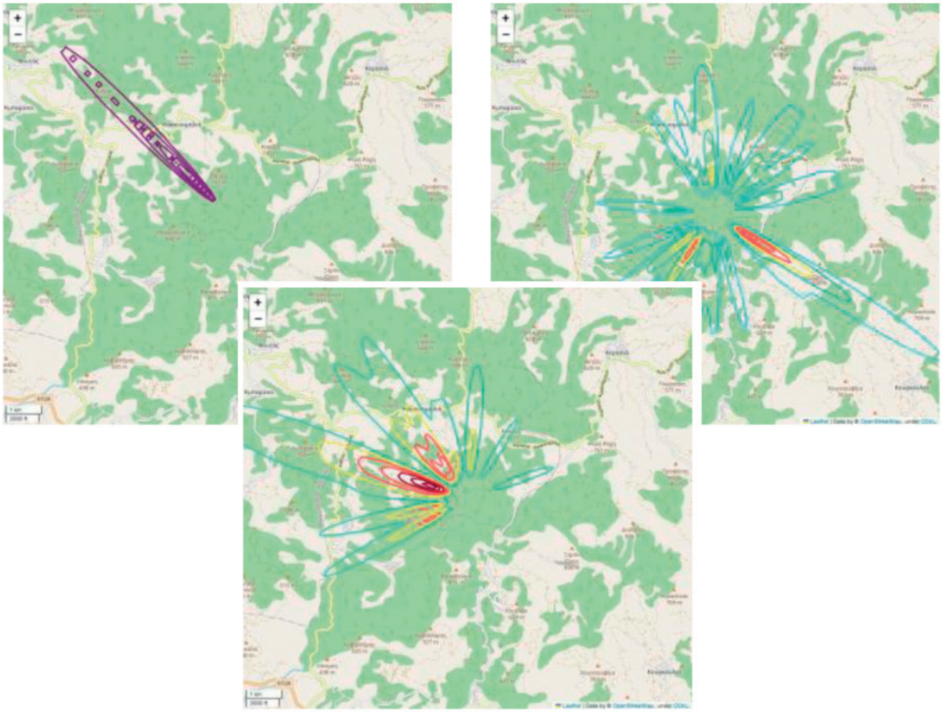

Figure 23. Different wind fluctuations determining wildfire ranges
Source: (SILVANUS D5.3, 2023)

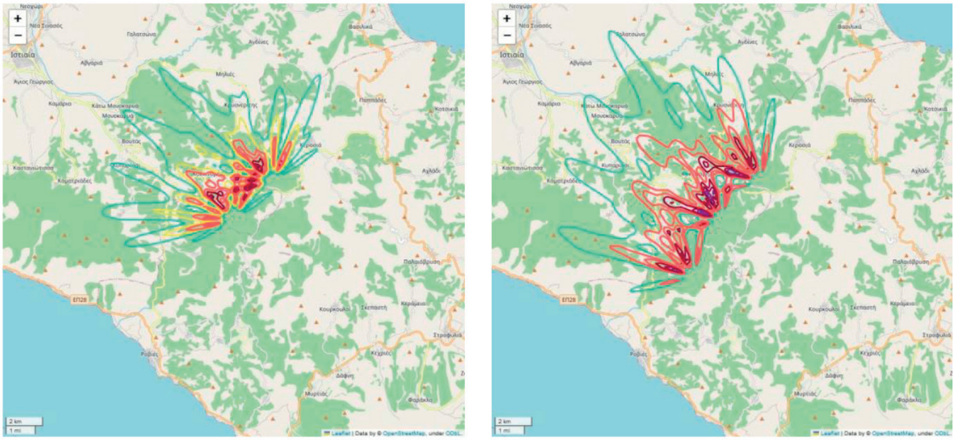

Figure 24. Multiple wildfire sources determining wildfire ranges
Source: (SILVANUS D5.3, 2023).

The natural direction is to integrate it to GIS (Hu et al., 2023). Thanks to this solution it is possible to make the forecast operational for firefighters and other wildfire responders. However, access to GIS environment is needed and technical support may prove to be necessary.

3.3.2. Operational protocol

The operational protocol related to the use of the fire spread forecast in wildfire response training should involve a universal process of wildfire response. Figure 25 presents such a process. In addition, process elements that may be supported by relevant assessment tool are also indicated.

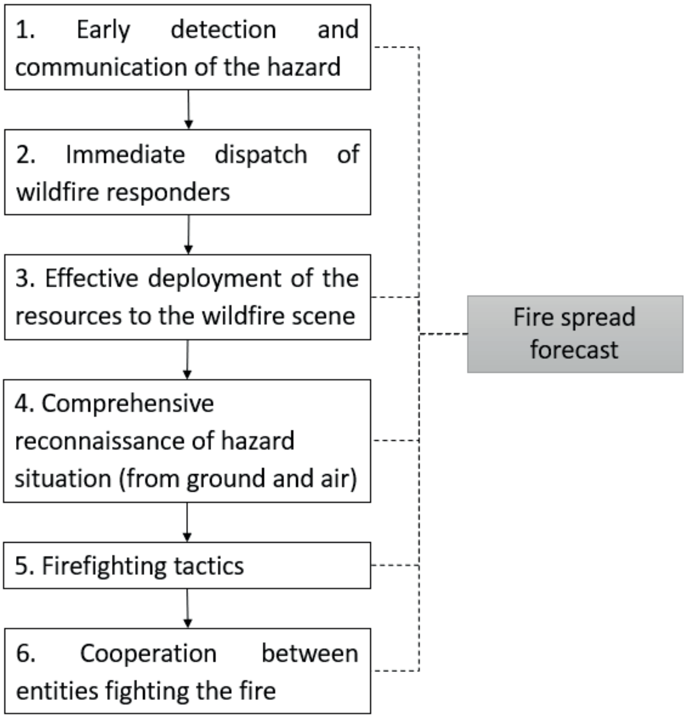

Figure 25. Application of fire spread forecast in support of wildfire response training
Source: own study

The technology impact is the most noticeable in case of early detection and communication of the hazard, effective deployment of resources to the wildfire scene, comprehensive reconnaissance of the hazard situation (from the ground and from the air), firefighting tactics and cooperation between entities involved in firefighting. They are wildfire response phases in which information provided by the forecast is of considerable importance for operational effectiveness and safety reasons. Table 11 contains examples on how to use fire spread forecast in particular phases described.

Table 11. Examples on how to use fire spread forecast in particular phases of wildfire response

No.	Phase	Examples
1	1. Early detection and communication of the hazard	1) Trainee indicates the most probable places where a wildfire may occur in the given time perspective. 2) Trainee analyses the riskiest areas in diverse weather conditions. 3) Trainee analyses different scenarios of hazard development.
2	3. Effective deployment of resources to the wildfire scene	1) Trainee adjusts arrival route to the wildfire scene on the basis of wildfire risk in different time perspectives. 2) Trainee seeks alternative directions and arrival roads in case of a wildfire outbreak that is reflected by relevant risk. 3) Trainee indicates relatively safe places to concentrate forces of wildfire responders.
3	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee analyses the wildfire scene to indicate places that could be in danger in the given time horizon. 2) Trainee indicates places to operate UAVs in wildfire conditions (as a rule outside the riskiest areas and on the path of the hazard development). 3) Trainee indicates places to operate UGVs in wildfire conditions (as a rule near the fire flanks).
4	5. Firefighting tactics	1) Trainee indicates the most probable directions of hazard development. 2) Trainee sets out defence lines on the basis of the fire spread forecast.
5	6. Cooperation between firefighting entities	1) Trainee indicates a place to gather firefighting resources (outside the riskiest areas of the wildfire scene). 2) Trainee navigates a helicopter or a plane according to direction of hazard development to make water drop for fire suppression from the air. 3) Trainee communicates with other trainees to exchange operational information related to hazard development.

Source: own study

The use of a fire spread forecast in wildfire response training is based on general operational activities. They are as follows:

1) Familiarisation with the training scenario.
2) Instruction for proper usage of the fire spread forecast and interpreting of its results or to get support from a trainer (the tool operator).
3) Pre-training conduct of the fire spread forecast on the semi-scenario (elements of training scenario) to find out kinds of information may be obtained from the tool.
4) Essential fire spread forecast to carry out the training scenario (directly by a trainee or indirectly with the support of a trainer).
5) Debriefing after the training and training evaluation.

As regards the fire spread forecast specifics, it is not easy to clarify in detail how it should be used. Furthermore, the protocol should be adjusted to cognitive abilities of trainees as some of them may require support to operate the tool. Another issue is to be aware of the probabilistic nature of the forecast. There is no 100% certainty that it will be fully reflected by the real fire scenario. For this reason, the training scenario may also deviate slightly from the forecast in order to emphasise its probabilistic nature.

3.3.3. Enhancement capabilities

During firefighter training, a valuable opportunity is to test the suitability of individual solutions. This is a viable assumption also for the fire spread forecast. As the forecast functionalities generally face operational expectations of firefighters and other wildfire responders, appropriate training may help verify them. Moreover, the scope of information to be collected and/or interpreted can be clarified.

The implementation of a fire spread forecast into fire training completes the training background and indicates possible scenarios for further development of the training. Attendees are able not only to get the general situational picture but also to think about it in terms of successive time horizons (for example after 12 hours, 24 hours). It is not easy to achieve in other ways, especially from the field perspective. Consequently, enhancement capabilities come up. They involve both the training and the forecast.

As far as the training-related preparation and pre-planning activities for wildfire response are concerned, the application of fire spread forecast allows achieving significant enhancement by:

a) focusing attention of training participants on areas characterised by the highest risk of fire development,
b) using the fire development risk as a factor that determines decisions to be made during such training,

c) operationalising emergency management and disaster management plans as regards the risk of fire development (including the cascading effect of a wildfire),
d) rationalising the deployment of firefighting resources on the scene in terms of fire risk values (including places for the concentration of forces),
e) focusing wildfire response efforts on areas characterised by the highest risk of fire development,
f) analysing fire development scenarios related to different weather conditions, land relief, results of firefighting efforts, natural barriers (for example water containers),
g) using real case studies as the basis.

As a rule, information about the development of a wildfire enables the firefighters to optimise their actions. It forces focusing on issues and areas that are the most important from the response effectiveness and safety viewpoints. This in turn allows collecting lessons learned even before the hazard occurs.

Focusing on the fire spread forecast, its application for training purposes of preparation and pre-planning activities for wildfire response may lead to technology enhancement by:

a) inspirations to devise new calculation mechanisms to obtain information about the risk,
b) new ways of integrating the forecast to GIS to visualise hazard scenarios easily, and to make their use in geo-spatial analysis possible,
c) developing new ideas for interpretation of the forecast output,
d) designing user-oriented solutions,
e) devising a user-friendly dashboard to visualise the forecast results.

The general idea to improve the technology is to confront it with the users and let them point out what needs to be improved (a tool, an algorithm, a mechanism, a technology solution) with end-users (especially with firefighters and forest services). The confrontation results should be understood as potential directions for improvements. As the fire spread forecast is not a standalone solution, strong correspondence with visualisation tools is required. This may offer additional enhancement capabilities (as regards the development of visualisation tools, for example new GIS software or functionalities).

In accordance with enhancement limitations, they are noticeable primarily in the case of the tools. The following aspects should be taken into account:

a) limited access to data,
b) limited access to visualisation tools,
c) low level of technology integration to visualisation tools,
d) differences in tool manipulation abilities of trainees,
e) stress related to usage of a tool,

f) difficulties in proper interpretation of the forecast output,
g) relatively high number of information sources to be analysed.

These issues determine the effectiveness of the training course. They may require addressing specific factors that affect the mental safety of trainees.

3.3.4. Safety issues for deployment of the technology

Deployment of the fire spread forecast means semi-direct contact with trainees. A training attendee is connected to the wildfire scene by technological means (generally via such visualisation equipment as a screen and/or a dashboard). The use of this tool gives rise to hazards for the users . From the training safety viewpoint, the following factors should be taken into consideration (Rączkowski, 2022):

1) Hazards associated with the movement of people.
2) Electrical shock.
3) Visual radiation.
4) Biological factors.
5) Mental burden.

Table 12 presents examples of conditions of hazard materialisation.

Table 12. Illustrative circumstances of hazard materialisation when implementing fire spread forecast into firefighters' training

No.	Hazard	Illustrative circumstances
1	Hazards of moving, loose, and protruding parts	a) Being hit by a screen. b) Stumbling over a computer post. c) Tripping over a cable.
2	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to the training infrastructure (a light fixture, an electrical socket).
3	Visual radiation	a) Radiation generated by screens.
4	Biological factors	a) Biological agents transmitted by other trainees (air ways). b) Biological agents accumulated on training infrastructure.
5	Mental burden	a) Situational stress. b) Stressful competition. c) Too many sources of information (information overload). d) Inability of using the assessment tool. e) Difficulties in correct interpretation of the forecast output.

Source: own study

The training risks may be minimised by the following prevention measures:

1) for hazards of moving, loose, sharp and protruding parts:
   a) to firmly fix screens and cables (for example to walls),
   b) to mark safety distances (at least 1 m) around the training platform and other training areas,
   c) to ensure order in the training zone;
2) for electrical shock:
   a) to check electrical devices before every training course,
   b) to work out safety procedures to respond to any physical damage in equipment and infrastructure;
3) for visual radiation:
   a) to ensure proper illumination in the training room;
4) for biological agents:
   a) to disinfect the training area after every scenario,
   b) to disinfect equipment after its use,
   c) to devise a biological safety manual,
   d) to verify the health condition of every trainee;
5) for mental burden:
   a) to minimise or eliminate competition elements from the training scenario,
   b) to ensure a friendly atmosphere during a training course,
   c) to ensure staff members to support trainees in the technical use of the assessment tool (including support in proper interpretation of the assessment results),
   d) to devise and share a short manual with procedures to properly interpret the forecast output.

The use of this tool results in a relatively low level of occupational risk (compared to the other tools discussed here). Its use typically involves an office job, which comes down to making simulations, visualising them and interpreting the results. The calculation is generally fully automated. Integration to GIS is required to make the forecast output operational for firefighters.

Chapter 4

Enhancement of preparation and pre-planning activities for wildfire response using reference operational end-technology tools for firefighter training

4.1. Fire monitoring using UAVs (drones)

4.1.1. Technology in a nutshell

UAVs are increasingly used in fire protection on woodland areas (Fellner, 2023). This typically involves deploying drones for firefighting and hazard detection operations. There is some promising research underway as to the use of UAVs for firefighting purposes (especially over terrain obstacles and/or when direct access to the fire site is not possible). These are currently in the development stage (Restas, 2022), although even at this stage they are characterised by high potential for implementation for rescue operations (Feltynowski, Zawistowski, 2018). The more significant and technology-matured role of drones is noticeable in the case of fire detection and monitoring (De Vivo et al., 2021; Al Ali, Alabady, 2022; Bailon-Ruiz et al., 2022).

Current developments in technology provide an optimistic view of the future of unmanned aerial vehicles and fire detection. This stems from new improvements in drone tracking (Feng, Katupitiya, 2022; Javed et al., 2023), coordination of drone swarm (Zelenka et al., 2023), and integration with other kinds of technologies (He et al., 2023). Consequently, the use of drones is said to be not only a detection means but rather an integral element of overall situation assessment process related to wildfire response. The idea is presented on Figure 26.

When considering wildfire detection, potential beneficiaries of drones are firefighters (commanders, drone operators, staff members, etc.), forest services (drone operators, staff members) as well as entities that conduct disaster management and emergency management (public administration decision makers and management centres). UAVs may be used directly (for example by an operator from fire service on the field) or indirectly (on the basis of wireless visualisations obtained thanks to drones operating in the danger zone).

UAVs can provide an overview of the forest fire situation . The picture is devised from the air perspective. This guarantees its basic functionality.

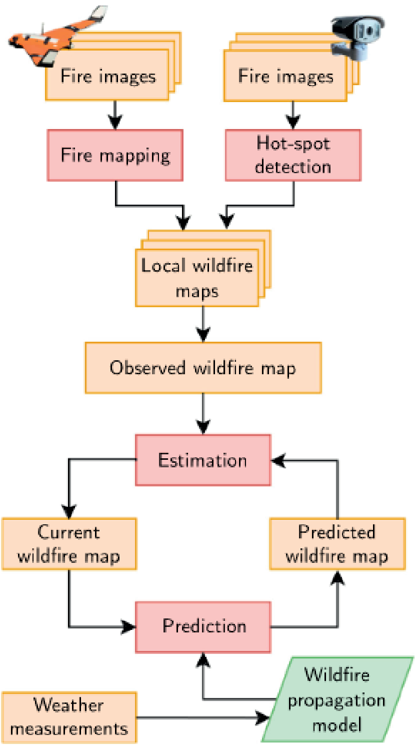

Figure 26. Fire detection with the use of a drone in overall situation assessment process related to wildfire response

Source: (Bailon-Ruiz et al., 2022)

As regards specific fire monitoring functionalities of drones, they can be described as follows:

a) to identify wildfire manifestations (smoke, flames, high temperature),
b) to monitor hazard development in the real time,
c) to identify objects that may pose derivative threats (for instance gas pipelines),
d) to identify people and animals in need of support (i. a. evacuation),
e) to identify firefighting resources and arrival routes,
f) to identify water sources,
g) to collect additional fire, terrain and weather information from specialised hyperspectral sensors.

Figure 27 shows an example visualisation of results on wildfire detection with the use of a drone integrated to fire detection at the Edge.

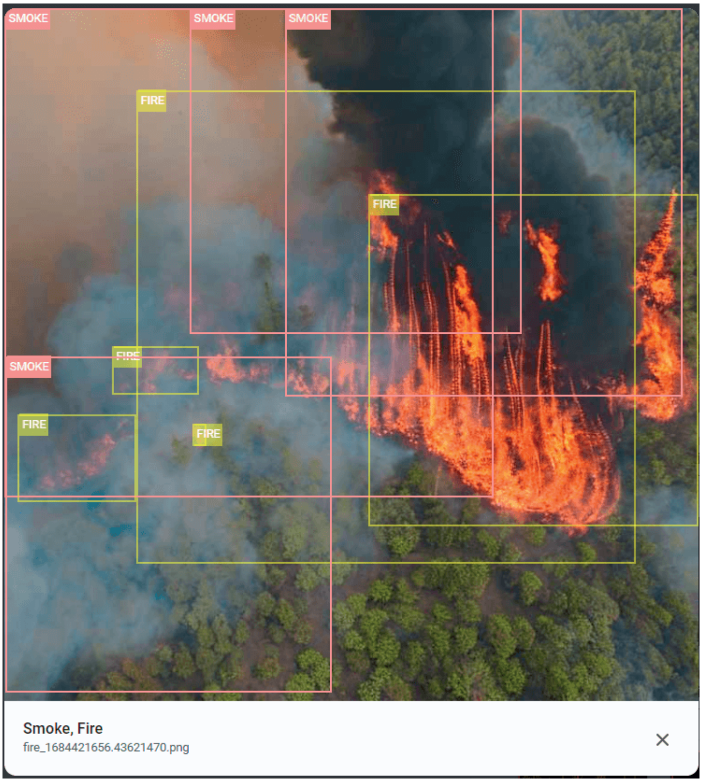

Figure 27. Visualisation of results of wildfire detection with the use of a drone integrated to fire detection at the Edge

Source: (SILVANUS, 2024)

The monitoring potential of drones stems from additional equipment that may be attached to them and to an overall system that they co-constitute. In case of firefighting operations, they typically comprise the following system elements:

a) unmanned platform (i.e., UAV),
b) control apparatus/ground control station,
c) sensors (RGB, thermal imaging, NDVI cameras, etc.),
d) data transmission equipment (control, telemetry, imagery, etc.),
e) flight support equipment (i.a., docking stations, tethered systems).

A drone as such is merely a tool. The system is the key element of fire monitoring and the possibilities it offers may significantly facilitate wildfire response. For example, Figure 28 presents the overview of selected systems for real-time wireless video transmission from UAV.

Figure 28. Overview of selected systems for real-time wireless video transmission from a UAV. On the left – Mobile Command Centre (RPASAR), on the right – ACO Streamer 4K LTEA (ACO Solutions)

Source: (RPASAR, 2022; Fellner, 2023)

Modern UAV solutions offer multiple opportunities to analyse what a drone sees. Figure 29 presents a view for a firefighter who conducts activities during a wildfire response action. This gives additional perspective for drone operator and command centre to analyse better what is going on during an action.

Firefighting training plays research role for drones and provides an opportunity to evaluate this technology in fire monitoring and other wildfire response activities. It is very important from the practical point of view as UAV technology is related to many operational threats and legal restrictions (Feltynowski, Zawistowski, 2018; Fellner, 2023).

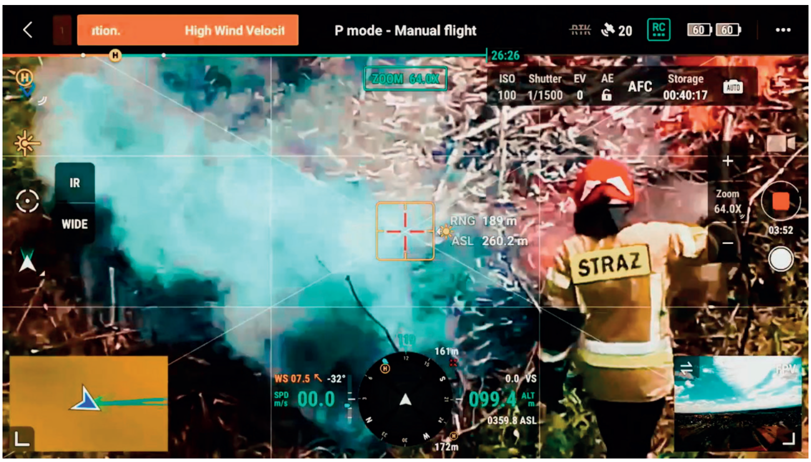

Figure 29. View of a wildfire scene from the perspective of a drone

Source: (Youtube, 2022; Fellner, 2023)

4.1.2. Operational protocol

The use of UAVs for fire monitoring, both in training and real firefighting operation, should be operationalised. It is necessary to indicate areas of drones' applications in wildfire response. The operational protocol needs to reflect the universal process of the response. This is significant to allow designing fire monitoring using UAVs coherently with other technologies. Figure 30 visualises logical relationships between fire monitoring using UAVs and elements of the process in the context of support of wildfire response training.

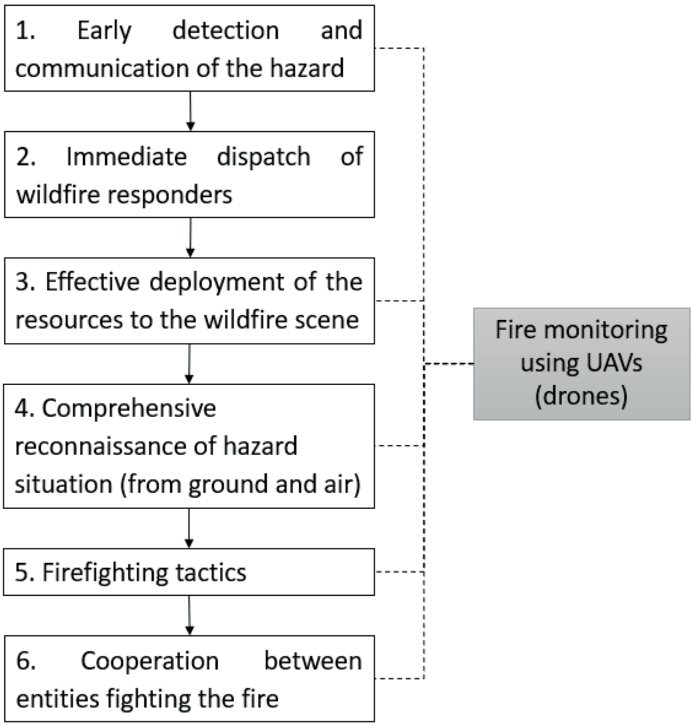

Figure 30. Application of fire monitoring using UAVs in support of wildfire response training
Source: own compilation

The technology impact is noticeable in most of phases associated with wildfire response and comprise early detection and communication of the hazard, effective deployment of the resources to the wildfire scene, comprehensive reconnaissance of the hazard situation (especially from the air), firefighting tactics, and cooperation between firefighting entities . This justifies that information collected by an UAV can be helpful for firefighters in almost the entire process of wildfire response. It also highlights potential areas of the technology implementation to firefighting training.

Table 13 contains examples on how to implement fire monitoring using UAVs into training activities as regards particular response phases. These could be ways to operationalise protocols of the technology use in firefighting training purposes.

Table 13. Examples on how to implement fire monitoring using UAVs into particular phases of wildfire response

No.	Phase	Examples
1	1. Early detection and communication of the hazard	1) Trainee confirms the detection of a hazard in a specific area. 2) Trainee verifies the reliability of information concerning hazard occurrence. 3) Trainee marks a preliminary zone where a wildfire has occurred given its specific manifestations (flames, smoke, thermal radiation).
2	3. Effective deployment of resources to the wildfire scene	1) Trainee adjusts the arrival route to the wildfire scene appropriately to location of hotspots. 2) Trainee seeks alternative directions and arrival roads in case the wildfire develops as reflected by location of hotspots.
3	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee analyses wildfire scene from the air perspective to collect basic reconnaissance information about hotspots' location. 2) Trainee analyses wildfire scene from an aerial perspective to gather basic reconnaissance information seeking elements that may pose derivative threats. 3) Trainee analyses wildfire scene from the air perspective to collect basic reconnaissance information related to people in need of help (for example in evacuation circumstances).
4	5. Firefighting tactics	1) Trainee marks a danger zone for further planning of firefighting tactics. 2) Trainee monitors the progress of the firefighting operation and checks it in accordance with tactical orders. 3) Trainee identifies threats that may affect the firefighters.
5	6. Cooperation between firefighting entities	1) Trainee marks the danger zone for further planning of cooperation between firefighting entities . 2) Trainee monitors the progress of overall response operation and checks it in accordance with tactical orders and disaster management standards. 3) Trainee identifies threats that may affect firefighting entities . 4) Trainee indicates physical areas where firefighters need support from other entities.

Source: own study

Consideration of all elements described in Table 13 may constitute the general operational protocol of the UAVs' use for firefighting in both training and in real-life circumstances. As regards the technical complexity of a drone and its operational implementation, an appropriate specific protocol should be divided into preparation protocol and detection protocol.

The specific operational protocol for preparation of a drone for a monitoring action is reflected by checklists to be completed by drone operator. The protocol that bases on a checklist that takes into account operational experience, guidance materials and the legal framework may consist in (Janik et al., 2021):

A. as regards 'Man' (any person involved in an operation, training, competency, division of tasks and assignment of responsibilities):
   1) "Operator and pilots are competent and/or proven (have appropriate licenses, drone logbook)".
   2) "Ensure the operator and pilots have appropriate authorization and approvals".
   3) "Pilots are fit to operate (use the IMSAFE checklist: illness, medication, stress, alcohol, fatigue and emotion)".
   4) "The division of duties and competences and roles are known".
B. as regards 'Machine' (type of vehicle, additional equipment, Ground Control Station, reliability, continuing airworthiness, technical documentation, and safety devices):
   5) "Visual inspection of the UAS (propellers, cover, etc.)".
   6) "Software in Ground Control Station and UAV is updated".
   7) "RGB camera works (if used)".
   8) "Thermal camera works (if used)".
   9) "Additional payload works (if used)".
   10) "Check the Ground Control Station (C2 links, screen, buttons, sticks, etc.)".
   11) "Calibration".
   12) "Battery is charged".
   13) "SC card is empty and in place".
   14) "Checking the power supply and operation of additional equipment (laptop, additional display, walkie-talkies)".
C. as regards 'Mission' (the purpose of the flight, tasks and difficulty level):
   15) "Mission is planned, the goal is known".
   16) "Path planning is done".
   17) "Geocache is established".
   18) "Failsafe is set".
   19) "Take-off site is safe and marked".

D. as regards ‘Management’ (operational instructions, checklists, procedures, legal bases, activity supervision and control):
    20) “The ways of communication between pilots and visual observers are established”.
    21) “The ways of communication between other first responders are established”.
    22) “Operational manual, ERP and checklist are in place”.
    23) “Instructions and technical documentations are in place”.
E. as regards ‘Medium’ (meteorological conditions, natural environment, topography and time of day):
    24) “Inspection of the take-off site and surrounding area, detection of potential obstacles”.
    25) “Weather conditions are met (KPI, wind, humidity, air temperature, etc.)”.
    26) “Weather forecasts”.

Operational protocols reflect that the use of UAV to detect fires in forest conditions requires additional manual preparation. This is why this kind of equipment is dedicated to educated and certified operators. From the practical point of view and as regards current firefighting standards they could be firefighters or supporting staff.

The situation is more complex when UAVs are integrated with specific technological solutions. The most common are as follows (Janik et al., 2021):

a) additional FPV cameras,
b) Automatic Dependent Surveillance–Broadcast (ADSB) receivers,
c) ADSB transmitters,
d) redundant power supply,
e) redundant communication systems,
f) appropriate structure,
g) parachute/airbag,
h) obstacle detection and avoidance systems.

Any deficiencies in the operational abilities of trainees should be covered by technical support staff and/or pre-prepared results of fire monitoring processes.

4.1.3. Enhancement capabilities

Training for firefighters is a good opportunity to use UAVs for fire monitoring purposes. This is important because trainees are typically practitioners that work in extremely difficult conditions, and are able to indicate enhancement suggestions. Firstly, the potential of UAVs may improve operational standards of the fire service and other wildfire responders. And secondly, firefighters’ needs, experience and expectations can determine the technology improvements.

As regards training-related preparation and pre-planning activities for wildfire response, the implementation of UAVs for fire monitoring in conditions of a forest fire allows achieving enhancement by:

a) indicating wildfire manifestations (flames, smoke, hotspots),
b) shaping operational picture related to a wildfire,
c) automating fire detection processes,
d) extending the fire monitored area,
e) using real case studies.

UAVs offers an additional pair of eyes to help analyse the wildfire scene. They also allow showing a different perspective in shaping the operational picture. Such an air perspective may be supplemented by on-ground reconnaissance teams and supplement the reconnaissance results. The teams can collect additional information about a wildfire and its conditions – information that is often hard to get in other ways. A wide spectrum of sensors increases the required potential. This is why training may be used to test and evaluate UAVs and UAVs-related operational procedures before they are implemented into firefighting practice.

In addition, given the needs, experience and expectations of firefighters in responding to fires, impressive opportunities for improvement can be reported. On such a basis, the following enhancement capabilities may be highlighted (Fellner, 2023):

A. as regards 'Man' (any person involved in an operation, training, competency, division of tasks, and assignment of responsibilities):
    a) analysing behavioural patterns of the operators and their operations with the use of drones,
    b) in-depth adaptation of screens and dashboards to human conditions and expectations,
    c) ergonomic improvements of drone manipulators;
B. as regards 'Machine' (type of vehicle, additional equipment, Ground Control Station, reliability, continuing airworthiness, technical documentation, and safety devices):
    a) developing additional slots for new detectors,
    b) optimising a set of slots for detectors in case of a particular UAV,
    c) working out heat-resistant drone constructions,
    d) rationalising battery solutions,
    e) ergonomic improvements of structural elements of a drone,
    f) inventing new sensors to be deployed in drones;
C. as regards 'Mission' (the purpose of the flight, tasks, and difficulty level):
    a) adjusting the flight schedule to wildfire response conditions,
    b) rationalising tasks to be considered by the drone operator,
    c) better understanding of professional firefighting language and reflecting it in drone operations;

D. as regards 'Management' (operational instructions, checklists, procedures, legal bases, activity supervision and control):
   a) formulating and/or evaluating specific operational instructions, checklists, procedures, legal bases, activity supervision and control,
   b) highlighting the necessity of adopting changes to management procedures that may be not appropriate to wildfire conditions,
   c) integrating the existing specific operational instructions, checklists, procedures, legal bases, activity supervision; and control;
E. as regards 'Medium' (meteorological conditions, natural environment, topography and time of day):
   a) integrating drone safety rules with weather forecast results,
   b) devising drone safety rules that are determined by the so-called 'fire weather',
   c) increasing drone potential to avoid difficult terrain obstacles,
   d) increasing drone potential to ensure flight stability in wildfire conditions (for example in smoke zone).

Any suggestion to technology providers to make UAVs more suitable for fire response relates to basic technology skills. This is why any significant improvement can be dealt with not only as wildfire-related innovation but also with a drone innovation. Such unique relationship has a significant impact on technology development and its direct use in practice.

As regards enhancement capabilities, they are noticeable both in case of the training and considering the drones. The following aspects should be considered:

1) as regards training-related preparation and pre-planning activities for wildfire response:
   a) access to drone operators (from fire service and/or external entities),
   b) strong dependence on technical staff support,
   c) high level of uncertainty related to weather conditions,
   d) operational risks (likelihood that something might go wrong),
   e) reconnaissance is time consuming and prolong training;
2) as regards fire detection using UAVs:
   a) stress related to usage of a tool,
   b) stress related to the use of technology,
   c) stress-tests for the devices may be destructive to them,
   d) technical dependency on sensors deployed to UAVs,
   e) necessity of ensuring batteries and/or charging possibilities in field conditions.

In case of UAVs, the practical limitations for enhancements are derived from the characteristics of the technology. The technology is not sufficiently develop of its widespread use in wildfire practice and requires firefighters to become prepared to implementing it in wildfire response.

4.1.4. Safety issues for deployment of the technology

Deployment of drones for fire monitoring to carry out preparation and pre-planning activities for wildfire response should be confronted with safety issues. This is also rational in the light of a training course as drones are used generally in field conditions. Consequently, the following safety factors (hazards, threats) should be indicated (Rączkowski, 2022):

1) Hazards of moving, loose and protruding parts.
2) Movement of people and equipment.
3) Fall from a height.
4) Electrical shock.
5) Fire-related hazards (thermal radiation, smoke, burn).
6) Microclimate.
7) Severe weather conditions.
8) Noise.
9) Visual radiation.
10) Chemical factors.
11) Biological factors.
12) Mental burden.

This complex set of factors is operationalised in Table 14 with relevant examples. They shed light onto possible circumstances of hazard/threat materialisation during the use of a drone in firefighting training.

Table 14. Examples of circumstances of the materialisation of hazards/threats when using drones for fire detection when training firefighters

No.	Hazard	Examples of circumstances
1	Hazards of moving, loose, and protruding parts	a) Being hit by a drone. b) Being hit by a screen c) Being hit by an environmental element (for example by a branch). d) Tripping over a land unevenness in the woods. e) Tripping over firefighting hose. f) Stumbling over a computer post. g) Tripping over a cable.
2	Movement of people and equipment	a) Being hit by a quad, a fire engine, etc. b) Collision with an aircraft and/or a helicopter. c) Damage caused by water drop for fire suppression from an aircraft and/or a helicopter ('Bambi bucket').
3	Fall from a height	a) Fall from a cliff, sinkhole and other terrain unevenness while using a drone.

Table 14 cont.

No.	Hazard	Examples of circumstances
4	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to the training infrastructure (a light fixture, an electrical socket).
5	Fire-related hazards (thermal radiation, smoke)	a) Thermal radiation from a fire while operating in danger zone. b) Smoke contamination while operating in danger zone.
6	Microclimate	a) Cold microclimate determined by weather.
7	Severe weather conditions	a) Strong wind. b) High temperature on a sunny day. c) Precipitation (heavy rain, snow, etc.). d) Dense fog.
8	Noise	a) Noise caused by firefighting equipment in field conditions.
9	Visual radiation	a) Solar radiation. b) Radiation from firefighting engines.
10	Chemical factors	a) Chemical substances generated by firefighting engines.
11	Biological factors	a) Biological agents transmitted by other trainees (air ways). b) Dangerous animals in the woods.
12	Mental burden	a) Situational stress. b) Inability of using the assessment tool. c) Technical problems with a drone.

Source: own study

On the basis of good occupational safety and health practices, the following preventive measures are suggested to reduce training risks related to the enumerated hazards/threats:

1) for hazards of moving, loose, sharp and protruding parts:
    a) to fix the screens and cables firmly (for example to walls),
    b) to fix firmly the drone devices,
    c) to mark safety distances (at least 1 m) around the training platform and other training areas,
    d) to ensure order in the training zone,
    e) to ensure protective shoes for trainees;
2) for movement of people and equipment:
    a) to mark walking paths in the operational centre,
    b) to order the training zone,
    c) to ensure visibility of engines and other equipment;

3) for fall from a height:
    a) to mark dangerous places on the training field,
    b) to plan training activities away from dangerous places on the training field;
4) for electrical shock:
    a) to check electrical devices before every training,
    b) to work out safety procedures to respond on any physical damage in equipment and infrastructure;
5) for fire-related hazards (thermal radiation, smoke):
    a) to stay in contact with training organisers who know where fire has started,
    b) to keep a distance from fire manifestations (flames, smoke),
    c) to ensure and secure an evacuation route and alternative evacuation road;
6) for microclimate:
    a) to wear clothes appropriate to weather conditions,
    b) to ensure beverages appropriate to weather conditions (either hot or cold);
7) for severe weather conditions:
    a) to ensure umbrella and other means of weather protection,
    b) to wear clothes appropriate for weather conditions,
    c) to ensure beverages adjusted to weather conditions (either hot or cold);
8) for noise:
    a) to use earplugs,
    b) to mark safety distances,
    c) to mark/isolate noisy places (if possible),
    d) to organise places for trainees possibly far from noisy places;
9) for visual radiation:
    a) to use personal protection means (for example sunglasses);
10) for chemical factors:
    a) to mark containers designated for chemical substances,
    b) to mark the danger zone and ensure safety distances;
11) for biological agents:
    a) to disinfect the training area after every scenario,
    b) to disinfect equipment after its use,
    c) to devise a biological safety manual,
    d) to verify to the health condition of every training participant,
    e) to ensure that a technical worker may selectively use a computer post with a dashboard;
12) for mental burden:
    a) to ensure a friendly atmosphere during a training,

b) o provide training to members of the technical staff in the technical use of drones and/or tools in order to visualise their use,
c) to organise a training course with a scenario that is relatively independent of the monitoring effectiveness (in case of low effectiveness on the use or technical problems with fire monitoring using drones).

Preparation and direct use of UAVs for needs of fire monitoring is dedicated to both firefighters and technology providers. Relatively high occupational risk is related to all training stakeholders. This highlights the necessity of ensuring safety not only for the trainees but also for technical staff members and other participants present in field conditions.

4.2. Use of UGVs (robots)

4.2.1. Technology in a nutshell

Unmanned ground vehicles (UGVs) are called robots. Their use for wildfire purposes is not very common as in the case of UAVs. However, some robot functionalities offer operational potential that could facilitate firefighters to respond to a wildfire. The functionalities reflect some of such capabilities of humanitarian drones as transport and delivery capabilities, surveying and monitoring capabilities, as well as communication and integration capabilities (Rejeb et al., 2021). They may noticeably increase safety and efficiency of the response. It is reported especially when a robot is integrated with additional equipment, sensors, etc.

As regards the above-mentioned issue, Figure 31 presents an example of a robot integrated with smoke detector, LIDAR and geo-localiser.

In addition, varied land relief may determine the use different UGV solutions. Considering the way UGVs move, there are generally two types of robots useful in forestry conditions - driving robots and walking robots. An example of the second one is shown in Figure 32. The deployment of UGVs to respond to fires depends on the type of terrain that can be run or walked on.

Main beneficiaries of UGVs use in case of a wildfire are firefighters, forest services, and disaster management teams. They are entities that require information that can be provided by a robot, which allows marking a danger zone, and making operational decisions. As for firefighters, robots may play also additional roles (for example as a platform, a transmitter or a mobile battery to UAV).

The essential operational difference between UAVs and UGVs is the perspective. In forest conditions some operational nuances may be unnoticeable from the air due to the presence of treetops and/or smoke. UGVs can provide information concerning the hazard and its circumstances directly from the ground level and complete the operational picture. This issue constitutes the main robot functionality in terms of

Figure 31. Robot integrated with a smoke detector, LIDAR and geo-localiser
Source: own resources

Figure 32. Walking robot integrated with LIDAR and geo-localiser
Source: own resources

a wildfire. The functionality is 'to stay next to or in front of a firefighter'. This reflects the essential supporting role of a robot. It is only meant to facilitate the job of wildfire responders.

Operationalisation of the main robot functionality in wildfire response allows indicating specific UGV functionalities. They are as follows (Rejeb et al., 2021; SILVANUS, 2024):

a) navigating UGVs autonomously to and from a fire front,
b) using the vehicles to report images, geolocation and the results of any partner sensors,
c) using LIDAR data to estimate local characteristics of the woods, such as leaf density and tree density,

d) transporting responders and their equipment to/from wildfire scene,
e) supporting the evacuation of responders,
f) supporting the evacuation of victims,
g) forming a communication hub to extend the radio communication range,
h) serving as a mobile platform for UAVs.

It should be emphasised that, given the maturity of robot technology, it is still too early to use UGVs as direct supporters to firefighters, and in particular to replace human responders on the wildfire scene by robots. Nowadays UGVs are unacceptably slow; navigation and pathfinding in difficult terrain conditions in the woods remain a serious challenge, robot construction is not sufficiently resilient to wildfire, and operational risk concerning damage and even robot loss (for instance because of flames or thermal radiation) is too high. However, technology development keeps providing new ideas to make UGVs more useful. Firefighting training can be a valuable opportunity to collect expectations and steer development into operationally defined tracks.

4.2.2. Operational protocol

Figure 33 visualises logical relationships between the use of UGVs and elements of the process of wildfire response in the context of support of wildfire response training.

The technology specifics determine a relatively small number of phases that refer to wildfire response. They are early detection and communication of the hazard, comprehensive reconnaissance of hazard situation (from the ground), firefighting tactics, and cooperation between firefighting entities. This proves that the use of UGVs can be helpful for firefighters in connection with some of the field activities in the domain of wildfire response. It also outlines areas in which the technology implementation may prove to be effective. Table 15 contains examples on how to implement UGVs in training activities with respect to particular response phases. These could be ways to operationalise protocols of the technology use in firefighting training purposes.

The use of robots for wildfire response purposes is not a widespread type of activity. One of the main reasons is the manual complexity and hi-tech specifics of UGVs. Consequently, when robots are deployed, technical support is necessary. A robot operator needs to help firefighters to make efull use of thepotential of this device in a way that corresponds to operational expectations. In addition, technical staff members should be available to visualise and explain results of robot operation. An example is presented on Figure 34. The figure regards 3D mapping based on LIDAR technology and path-tracking functionality[3].

[3] The functionality of path-tracking allows the transfer of geo-information collected by a robot to an operational centre and/or sharing it with other robots.

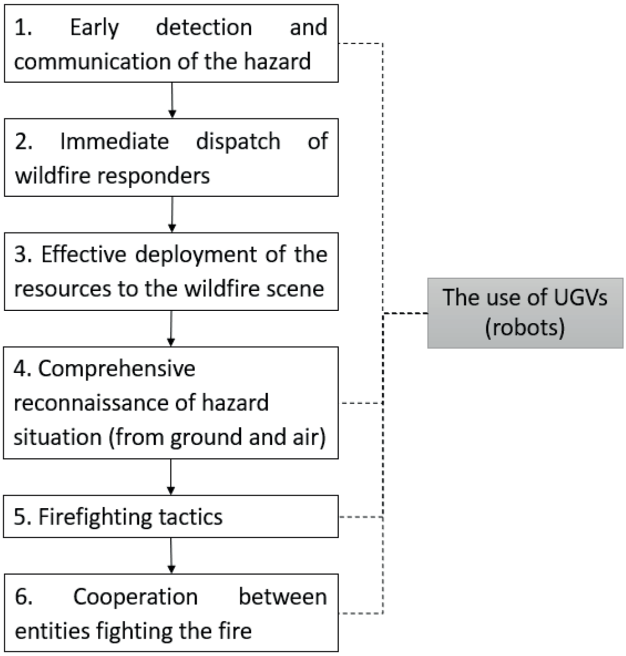

Figure 33. Application of UGVs (robots) in support of wildfire response training
Source: own study

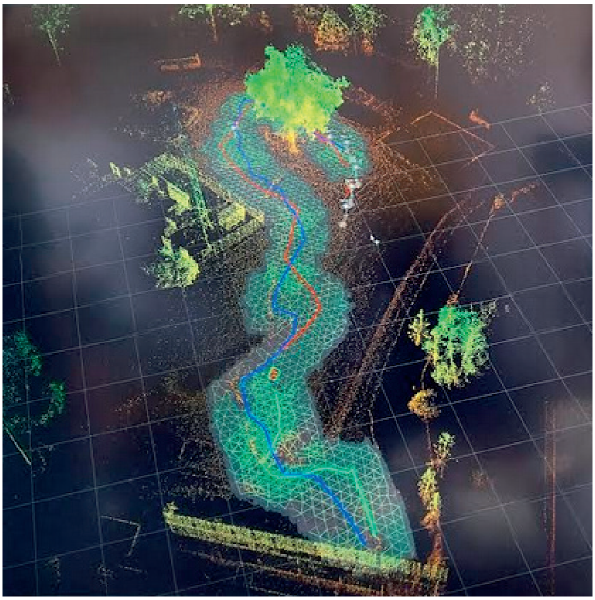

Figure 34. 3D mapping based on LIDAR technology and path-tracking functionality
Source: own study

Table 15. Examples on how to implement fire detection using UAVs in particular phases of wildfire response

No.	Phase	Examples
1	1. Early detection and communication of the hazard	1) Trainee confirms detection of a hazard in a specific area. 2) Trainee verifies the reliability of information concerning hazard occurrence. 3) Trainee marks a preliminary zone where a wildfire occurred has occurred given its specific manifestations (flames, smoke, thermal radiation).
2	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee analyses the wildfire scene from the ground perspective to gather basic reconnaissance information about the location of hotspots. 2) Trainee analyses the wildfire scene from the ground perspective to collect basic reconnaissance information seeking elements that may pose derivative threats. 3) Trainee analyses the wildfire scene from the ground perspective to collect basic reconnaissance information related to people in need of help (for example in evacuation circumstances). 4) Trainee analyses the density of trees that may affect the fire risk.
		5) Trainee indicates communication routes on the field. 6) Trainee integrates UGV with UAV and uses them together to conduct air-ground reconnaissance.
3	5. Firefighting tactics	1) Trainee designates the danger zone for further planning of firefighting tactics. 2) Trainee identifies threats that may affect firefighters.
4	6. Cooperation between firefighting entities	1) Trainee marks danger zone for further planning of cooperation between firefighting entities . 2) Trainee identifies threats that may affect firefighting entities. 3) Trainee indicates physical areas where firefighters need support from other entities. 4) Trainee uses UGV to extend the radio communication range. 5) Trainee uses UGV to transport heavy firefighting equipment. 6) Trainee builds a firefighting post with the use of UGVs. 7) Trainee uses UGVs to evacuate a victim found on the wildfire scene.

Source: own study

4.2.3. Enhancement capabilities

The relatively early stage of development of robot technology is an opportunity to directly improve processes in a way that takes into account the operational needs and expectations of firefighters.

As far as training-related preparation and pre-planning activities for wildfire response are concerned, the use of robots allows achieving enhancement by:

a) shortening the time between ignition of a wildfire and its identification,
b) undertaking immediate warning activities,
c) shaping the operational picture related to a wildfire,
d) automating fire detection processes,
e) extending the area covered by fire monitoring,
f) assisting firefighters in transporting heavy equipment,
g) ensuring basic evacuation functionality,
h) forming a quasi-mobile firefighting post[4],
i) basing on real case studies.

Every possibility to facilitate firefighting work in difficult forest conditions provides a good opportunity for enhancement. A robot may go where it is too dangerous for a human to go, it can see more than a firefighter thanks to multiple sensors, it is strong enough to carry heavy equipment, and it is more resilient to wildfire manifestations than a human. These aspects shed light on possible directions for further development of robot technologies.

As regards UGVs, the use of robots in training-related preparation and pre-planning activities for wildfire response allows achieving technology enhancement by:

1) checking the technical performance of robot solutions on the field,
2) creating additional slots for new detectors,
3) creating additional slots for additional equipment,
4) optimising a set of slots for detectors in case of a specific UGV,
5) optimising a set of slots for additional equipment in case of a specific UGV,
6) providing heat-resistant robot structure,
7) rationalising battery solutions,
8) ergonomic improvements of robot structural elements,
9) inventing new sensors to be deployed to robots.

Wildfire conditions may define stress tests for robots and test them in real or quasi-real circumstances. A difficult terrain, severe weather conditions and an extensive catalogue of operational hazards co-constitute a valuable testing ground for robot solutions. It can be assumed that meeting the relevant challenges means

[4] The quasi-mobile firefighting post means the post that is mobile before water fills the fire hose. After this moment every movement of a robot requires support from a firefighter or operator due to the weight of the firefighting line (for example one section of 52 mm diameter hose filled with water weighs approximately 50 kg).

developing the technology as a whole, with a positive impact on other areas of its implementation.

As far as enhancement capabilities are concerned, they are noticeable both in the case of the training and with respect to robots. There is a need to take into account the following issues:

1) as regards training-related preparation and pre-planning activities for wildfire response:
   a) access to robot operators (typically from outside the fire service and other kinds of wildfire responders),
   b) strong dependence on technical staff support,
   c) hi-tech specifics of robot solutions,
   d) high level of uncertainty with respect to weather conditions,
   e) operational risks (that something could go wrong),
   f) slow movements of the robot are time consuming and may extend the training;
2) as regards the use of UGVs:
   a) stress related to the use of a tool,
   b) stress related to the use of technology,
   c) stress-tests for the devices may be destructive to them,
   d) technical dependency on sensors deployed in UGVs,
   e) relatively short distance between a robot and its operator,
   f) necessity of ensuring batteries and/or charging possibilities in field conditions.

As far as UGV limits for enhancements are concerned, these are derived from the specifics of the technology (as with UAVs). The technology is not sufficiently developed to allow its extensive use in wildfire response. In addition, the technology needs to prepare firefighters to implement it to the response and access to external support is required.

4.2.4. Safety issues for deployment of the technology

When robots are deployed, some specific hazards may occur. There is a need of confronting the deployment with safety issues. This is additionally justified as UGVs are generally used in field conditions (in wildland). Consequently, the following safety factors (hazards, threats) should be specified (Rączkowski, 2022):

1) Hazards of moving, loose, and protruding parts.
2) Movement of people and equipment.
3) Fall from a height.
4) Electrical shock.
5) Fire-related hazards (thermal radiation, smoke, burn).
6) Microclimate.

7) Severe weather conditions.
8) Noise.
9) Visual radiation.
10) Chemical factors.
11) Biological factors.
12) Mental burden.

These factors are operationalised in Table 16 with relevant examples. They shed a light on possible circumstances of hazard/threat materialisation during the use of a robot in firefighting training.

Table 16. Examples of circumstances of the materialisation of hazards/threats when using drones for fire detection during firefighter training

No.	Hazard	Illustrative circumstances
1	Hazards of moving, loose, and protruding parts	a) Being hit by a drone. b) Being hit by additional equipment. c) Being hit by a screen. d) Being hit by an environmental element (for example by a branch). e) Stumbling on a land unevenness in the woods. f) Tripping over firefighting hose. g) Stumbling on a computer post. h) Tripping over a cable.
2	Movement of people and equipment	a) Being hit by a robot. b) Being hit by a quad, a fire engine, etc. c) Collision of UGV with a quad, a fire engine, etc. d) Damage from water drop for fire suppression from the air from an aircraft and/or a helicopter ('Bambi bucket').
3	Fall from the height	a) Fall from a cliff, sinkhole and other unevenness of the terrain while using a robot.
4	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to a robot. c) Physical damage to the training infrastructure (a light fixture, an electrical socket).
5	Fire-related hazards (thermal radiation, smoke)	a) Thermal radiation from a fire while operating in danger zone. b) Smoke contamination while operating in danger zone.
6	Microclimate	a) Cold microclimate determined by weather.
7	Severe weather conditions	a) Strong wind. b) High temperature on a sunny day. c) Precipitation (heavy rain, snow, etc.). d) Dense fog.

Table 16 cont.

No.	Hazard	Illustrative circumstances
8	Noise	a) Noise caused by firefighting equipment in field conditions.
9	Visual radiation	a) Solar radiation. b) Radiation from firefighting engines.
10	Chemical factors	a) Chemical substances generated by a robot. b) Chemical substances generated by firefighting engines.
11	Biological factors	a) Biological agents transmitted by other trainees (air ways). b) Biological agents accumulated on training infrastructure and devices. c) Dangerous animals in the woods.
12	Mental burden	a) Situational stress. b) Inability of using the assessment tool. c) Technical problems with a robot.

Source: own compilation

Respecting good occupational safety and health practices allows establishing the following prevention measures to reduce training risks related to the hazards/threats enumerated:

1) for hazards of moving, loose, sharp and protruding parts:
   a) to fix firmly the robot devices,
   b) to fix firmly the screens and cables (for example to walls),
   c) to mark safety distances (at least 1 m) around the training platform and other training areas,
   d) to ensure two operators to one robot,
   e) to ensure order in the training zone,
   f) to ensure protective shoes for trainees;
2) for movement of people and equipment:
   a) to mark walking paths in the operational centre,
   b) to order the training zone,
   c) to ensure visibility of engines and other equipment,
   d) to ensure two operators per one robot;
3) for fall from a height:
   a) to mark dangerous places on the training field,
   b) to plan training activities far away from dangerous places on the training field,
   c) to ensure two operators per one robot;
4) for electrical shock:
   a) to check electrical devices before every training course,

   b) to devise safety procedures to respond on any physical damage to equipment and infrastructure;
5) for fire-related hazards (thermal radiation, smoke):
   a) to remain in contact with training organisers who know where the fire has broken out,
   b) to keep a distance from fire manifestations (flames, smoke),
   c) to ensure and secure an evacuation route and an alternative evacuation route,
   d) to provide personal protection means;
6) for microclimate:
   a) to wear clothes appropriate to weather conditions,
   b) to ensure beverages appropriate to weather conditions (either hot or cold ones);
7) for severe weather conditions:
   a) to ensure an umbrella and other means suitable for protection against weather conditions,
   b) to wear clothes appropriate to weather conditions,
   c) to ensure beverages appropriate to weather conditions (either hot or cold ones);
8) for noise:
   a) to use earplugs,
   b) to mark safety distances,
   c) to mark/isolate noisy places (if possible),
   d) to organise places for trainees as far away as possible from noisy places;
9) for visual radiation:
   a) to use personal protection means (for example sunglasses);
10) for chemical factors:
   a) to mark containers for chemical substances,
   b) to mark the danger zone and ensure safety distances,
   c) to provide personal protection means,
   d) to ensure technical support team for any maintenance and service activities in the field;
11) for biological agents:
   a) to disinfect the training area after every scenario,
   b) to disinfect equipment after its use,
   c) to devise a biological safety manual,
   d) to verify the health condition of every trainee,
   e) to ensure that a technical worker can selectively use the computer post with a dashboard;
12) for mental burden:
   a) to ensure a friendly atmosphere during a training course,

b) to provide training to members of the technical staff in the technical use of robots and/or tools to visualise their usage,
c) to organise a training course with a scenario that is relatively independent of the detection effectiveness (in case of low effectiveness on the use or technical problems with fire detection using robots).

Preparation and direct use of UGVs is generally dedicated to technology providers who are not often well prepared to operate in the field conditions. They may be also not aware of specific hazards/threats. This highlights the necessity to ensure safety not only for trainees but also for technical staff members and other participants that are located in field conditions. The good practice is to indicate a safety officer to monitor safety issues during a training course, and to be ready to help trainees in case of an emergency.

4.3. Forward Command Centre

4.3.1. Technology in a nutshell

The Forward Command Centre is a kind of ad hoc unit established to support decision makers (commanders, emergency managers, disaster managers, crisis managers, etc.) on the field. It is characteristic for serious and/or long-term actions related to chemical spills (EU-SENSE, 2022), radiation accidents (EU-RADION, 2024), floods, etc. As regards wildfire response, the centre is typically organised by the fire service. It is allocated directly in the danger zone or nearby (the second option is more common due to personal safety of firefighters and other rescuers). This allows better understanding of the danger situation and simplifies management activities. There are different standards for organising a Forward Command Centre with respect to operational context, situational forecast, cooperating entities, and technologies used (Clark et al., 2011). Focusing on the technologies, the formula of the Forward Command Centre is very valuable to integrate different solutions and tools to increase analytical and communicational potential of this unit. For example, the centre software may be integrated to IoT (Ten Brink et al. 2022), satellite communication tools and radio systems (Vallejo, 2023). There is also space for computers and computational software to carry out analyses and simulations (EU-SENSE, 2022).

The general idea of the Forward Command Centre in the overall commanding system in wildfire response is presented on Figure 35.

The Forward Command Centre is to enhance analytical and commanding potential during wildfire response. This is why main beneficiaries of this technology are commanders, action staff members, forest managers and forest management centres, emergency managers and emergency management centres,

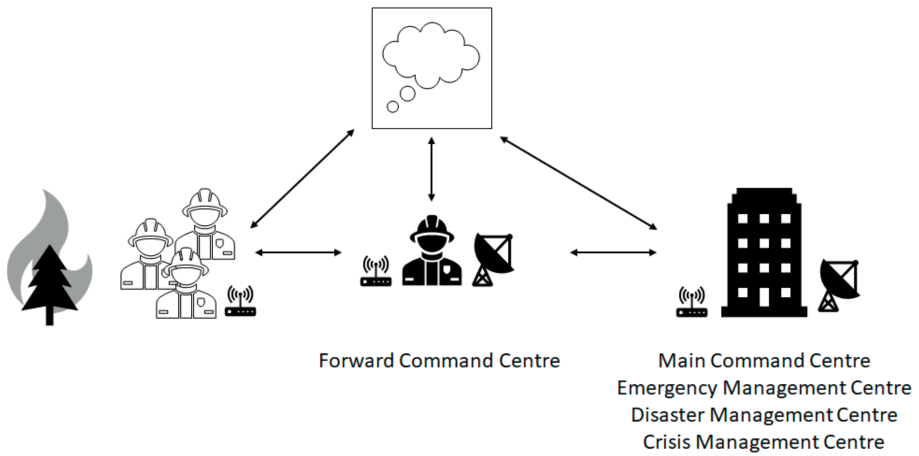

Figure 35. General idea of the Forward Command Centre in the overall commanding system in wildfire response

Source: own compilation

disaster managers and disaster management centres, crisis managers and crisis management centres. Relevant groups of stakeholders are firefighters, forest services, armed forces, public administration, police troops, critical infrastructure operators, etc. It is necessary to emphasise that every entity with information and other resources valuable for the purposes of wildfire response is welcome in supporting commanders, managers, analysts and focal points when the centre is in operation. Consequently, the centre formula allows involving all stakeholders who are interested in effective firefighting operation, evacuation, environmental protection, and/or protection of critical infrastructure related to a wildfire.

In accordance with general functionalities, the Forward Command Centre may (Belanger, 2023):

a) enhance situational awareness,
b) improve communication,
c) improve coordination,
d) centralise resource management,
e) streamline incident tracking and documentation,
f) assist in training and preparedness purposes.

From the viewpoint of a firefighter responding to a wildfire, these functionalities can be conceptualised as follows (i.a.):

a) technical and functional integrating to different data sources,
b) collecting of multiple kinds of data,
c) making data analyses,
d) shaping the situational picture,
e) working out response strategies,

f) supporting decision makers,
g) delivering information (including orders) to a commander and field firefighters,
h) structuring communication (also being a communication hub that connects field firefighters, commanders, action staff members and other stakeholders),
i) ensuring communication channels,
j) ensuring the continuity of communication regardless of the impeding issues,
k) gathering information about cooperating entities,
l) managing the cooperation between firefighting entities in a forest area,
m) monitoring of a wildfire,
n) monitoring of the status of wildfire response,
o) supporting the dispatching of new resources to the wildfire scene,
p) monitoring of resources already dispatched to the wildfire scene,
q) managing shifts and fluctuation of human resources during an action,
r) filling in documentation concerning the action,
s) sending to training courses for firefighters,
t) increasing operational preparedness of firefighters to use the centre when necessary to handle wildfire management.

There could be many ideas on how to organise the Forward Command Centre. An interesting approach has been devised in the SILVANUS project. The centre is the focal point of the overall information management process related to the use of many different technologies (SILVANUS, 2024). Its placement is presented on Figure 36.

The centre is said to be the place that makes the fire commander be able to manage the firefighting operation. The organisational formula of the centre is flexible, and may be organised in a vehicle, a building, or in another place which is relatively close to wildfire response scene. A very important aspect is to ensure that the commander may use multiple technological functionalities (for example fire detection using IoT devices, the fire spread forecast, resource allocation of response teams, priority resource allocation based on forest fire probability, evacuation route planning), and this is technically possible via a laptop, a tablet or another commonly available device. The centre may also compile data and information from multiple edge devices (robots, drones, sensors). In addition, different centres can be integrated to different functionalities and tools. This will essentially determine their roles with respect to wildfire response management (for instance the communication centre, the decision support centre, the analytical centre).

The operational potential of the Forward Command Centre lies in the integrated technologies. The more technologies, the more possibilities to support data collection, analyses, decision processes and communication. However, the increase in technological complexity entails an increase in difficulties of using the centre in

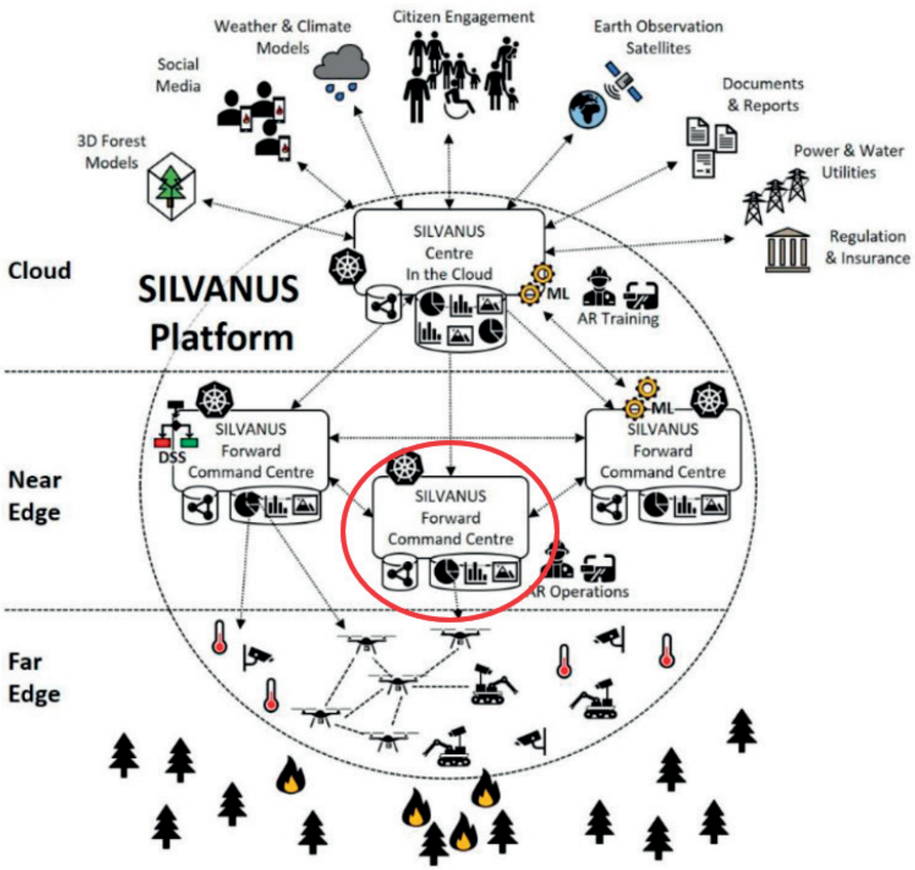

Figure 36. Application of the Forward Command Centre in overall information management process related to the use of SILVANUS technologies

Source: own study on the basis of (Mojir et al., 2023)

practice. Consequently, comprehensive training is needed to make stakeholders aware of functionalities offered by the centre and to familiarise them with new operational capabilities.

4.3.2. Operational protocol

The use of the Forward Command Centre in training for firefighters can be described in close relation to particular phases of wildfire response. This indicates a broad implementation potential of technology not only to real firefighting actions but also in preparation and pre-planning activities. Logical relationships between the use of the centre and elements of the wildfire response process in the context of support of wildfire response training is presented on Figure 37.

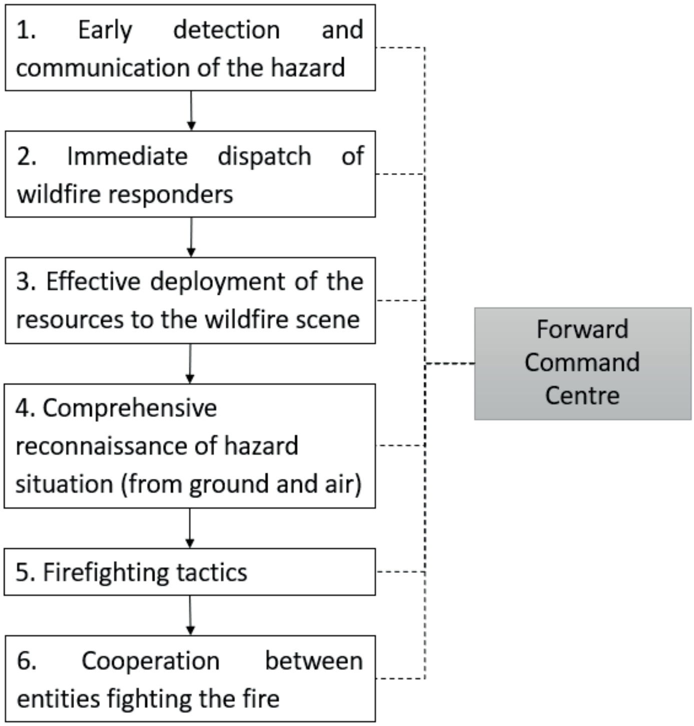

Figure 37. Role of the Forward Command Centre in support of wildfire response training
Source: own study

The technology is reported to shape preparation and pre-planning activities such as training for firefighters relating to all phases of wildfire response. They early comprise detection and communication of the hazard, immediate disposal of wildfire responders, effective deployment of resources to the wildfire scene, comprehensive reconnaissance of the hazard situation (from the ground and from the air), firefighting tactics, and cooperation between firefighting entities. This justifies that the Forward Command Centre is a valuable tool for a wide variety of different response contexts and can be used in many training scenarios. During the training the centre can be the only one training station or one of more of such stations (next to, for example, the drone operation point, the robot operation point, firefighting vehicle, firefighting post). Moreover, using the centre allows formulating training scenarios that cover one or more phases of the response. Table 17 lists examples on how to implement the Forward Command Centre into training activities as regards particular response phases. The list states a reference protocol of the technology use in firefighting training purposes.

Table 17. Examples on how to implement Forward Command Centre in particular phases of wildfire response

No.	Phase	Examples
1	1. Early detection and communication of the hazard	1) Trainee reports a fire detection signal from different sources (sensors). 2) Trainee confirms the alarm using other systems (for example cameras) or by radio communication to the reconnaissance team. 3) Trainee monitors videos and photos from drones and robots to detect new hotspots. 4) Trainee uses the IT dashboard to communicate new hotspots to other stakeholders.
2	2. Immediate dispatch of wildfire responders	1) Trainee analyses the hazard situation to dispatch wildfire resources that are quantitatively and qualitatively adequate to the situational picture. 2) Trainee indicates wildfire resources to be sent to the scene. 3) Trainee evaluates the amount of response resources on the basis of an updated situational picture and dispatches additional resources if necessary.
3	3. Effective deployment of the resources to the wildfire scene	1) Trainee adjusts the arrival route to the wildfire scene taking into account the location of hotspots, smoke, terrain obstacles, and evacuation routes. 2) Trainee evaluates the arrival route on the basis of the fire spread forecast. 3) Trainee seeks alternative directions and arrival routes in case the wildfire develops as reflected by location of hotspots and smoke.
4	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee analyses sensor readings, pictures and movies collected by the Edge tools and reports obtained from drone operators and robot operators to verify situational picture. 2) Trainee verifies accessible sources of information and asks firefighters to check their correctness. 3) Trainee analyses the vulnerability of the woods considering their biodiversity, set of roads, potential defence lines, and water sources. 4) Trainee uses analytical tools (for example the fire spread forecast) and decision support systems (evacuation route planning, resource allocation of response teams, etc.) to make the reconnaissance complete. 5) Trainee discusses the gathered information and develops the reconnaissance report to be shared among other stakeholders.

Table 17 cont.

No.	Phase	Examples
5	5. Firefighting tactics	1) Trainee monitors the range of the danger zone to plan firefighting tactics. 2) Trainee monitors the location and number of hotspots to plan firefighting tactics. 3) Trainee analysis the location of natural defence lines to plan the response approach. 4) Trainee makes an analysis of the situational picture to evaluate firefighting tactics if necessary.
6	6. Cooperation between firefighting entities	1) Trainee shares information about the range of the danger zone (smoke) and location and the number of hotspots with cooperators (for example the forest service and public administration). 2) Trainee gives orders to firefighters to increase the effectiveness of the cooperation. 3) Trainee coordinates the involvement of other entities to increase the effectiveness of the cooperation. 4) Trainee monitors communication among stakeholders.

Source: own study

Wildfire response training for firefighters implemented by the Forward Command Centre requires following general operational activities. It is necessary to consider implementation examples as well as integrated technologies and the general way in which they may be used comprehensively. The following activities should be taken into consideration:

1) Selecting the desired form of the centre (a vehicle, a building, a field, etc.).
2) Organisation of physical components of the centre (infrastructure, equipment, etc.).
3) Physical integration of technologies (for example drones, robots, IoT devices).
4) Software integration of computational tools, decision support systems and/or societal involvement tools.
5) Functional integration of the Forward Command Centre (for example sensor readings, generating pictures and/or movies, transferring data, communication flows).
6) Familiarisation with the training scenario.
7) Instruction for proper use of centre functionalities or obtaining support from a trainer (a tool operator).
8) Pre-training use of the centre for a semi-scenario (elements of a training scenario) to allow familiarisation with functionalities and areas of their use when responding to a wildfire.

9) Essential use of the centre to conduct a training scenario (directly by a trainee or indirectly with the support of a trainer).
10) Debriefing after the training and training evaluation.

The use of the Forward Command Centre requires complex and comprehensive preparation for a training course. The more functionalities are to be deployed, the more efforts are expected to make the training logically structured and effective. This also depends on the training scenario and the general idea on how the centre could be used for training purposes. The flexible organisational formula of the Forward Command Centre facilitates shaping the scenarios in many directions and referring to multiple aspects (for example coordination of line firefighters, support in working out of orders, gathering data, data analysis, evaluation of operational picture). Not all of the functionalities need to be used for a particular centre, a particular scenario, or even a particular training course. This emphasises the high training and technological value of the centre as regards enhancement capabilities for both preparation and pre-planning activities in wildfire response, and the technology itself.

4.3.3. Enhancement capabilities

Enhancement capabilities related to the use of the Forward Command Centre are twofold. Firstly, this technology may significantly enhance the effectiveness of preparation and pre-planning activities for wildfire response by streamlining analytical, communication and decision-making potential of firefighters. Secondly, training for firefighters is said to be a good occasion to identify operational needs, expectations and practical factors that impede implementation of the centre formula to the practice of firefighting in the woods. The two should be borne in mind when considering better response to the analysed hazard. Moreover, the Forward Command Centre can be interpreted as a platform to verify the usefulness of other technologies because it is able to integrate them into a single complex solution. From this point of view, multiple tools and solutions may be tested and implemented for different configurations of functionalities meant to facilitate preparation and pre-planning activities for wildfire response, by firefighters and by other safety entities.

As far as training-related preparation and pre-planning activities for wildfire response are concerned, the use of the Forward Command Centre allows achieving enhancement by (i.a.):

a) shortening the time between materialisation of wildfire manifestations (flames and smoke) and their reporting,
b) shortening the time for confirmation of the hazard occurrence from multiple sources of information,
c) automation of fire monitoring,
d) automation of monitoring of response operations,

e) extending the area covered by fire monitoring,
f) adjusting the area covered by fire monitoring to current operational needs (for example by the use of drones or robots),
g) minimising the risk of false positives in the fire detection process,
h) decreasing operational risks related to cooperation between different entities (including the fire service),
i) increasing safety for firefighters by replacing some them from the field (for instance limiting the number of reconnaissance teams),
j) immediate undertaking of warning activities,
k) shaping the operational picture related to a wildfire,
l) assessment of the permanent operational picture of a wildfire,
m) basing on real data,
n) making communication between entities more effective,
o) using cloud solutions to share information about a wildfire and response operations,
p) possibility of covering all fire scenarios,
q) using AI algorithms to identify derivative threats of a wildfire (for example when critical infrastructure is placed in a danger zone),
r) better understanding of wildfire conditions.

Considerable enhancement capabilities depend on technologies integrated to the centre and functionalities that increase the operational potential of firefighters. Capacities are derived from opportunities generated by technologies. From the practical point of view, bigger enhancement opportunities are noticeable in the edge technologies that have been already applied to firefighting operation in the woods (for example drones, cameras, communication tools). Lesser chances can be reported in relatively new solutions such as AI, robots and IoT. A separate issue is the use of decision support systems. They often require access to the Internet or other communication environment. And this may typically prove to be difficult in the woods. However, the development of communication technologies may be accompanied by increasing possibilities to make relevant enhancements.

As far as the technology viewpoint is concerned, implementation of the Forward Command Centre to preparation and pre-planning activities for wildfire response (putting special focus on training for firefighters) may inspire to seek improvements by:

a) new kinds of integrated edge solutions,
b) new kinds of used sensor data,
c) closer integration of technologies,
d) more effective platform for technology integration,
e) more effective algorithms for data analyses,
f) new ways for visualising analysis results,

g) connection to GIS visualisation and analytical tools (for example network analyst),
h) designing a user-friendly desktop,
i) focus on a thorough reduction of false alarms,
j) more effective communication flows,
k) designing a dashboard and other visualisation tools for intuitive use by firefighters,
l) new forms for deployment of the Forward Command Centre (new types of vehicles, deployment to a quad),
m) new end-edges to use the centre functionalities (for example a portable device with a screen and connection to the cloud data base).

A general way to achieve improvements in this case is to be open to suggestions from firefighters and face their operational needs. From the practical point of view, they should ascribe into ensuring personal safety for line firefighters, shaping situational awareness, and supporting firefighting systems. The second important issue is to monitor the development of integrated technologies and adjust the Forward Command Centre formula to new enhancement capabilities. The centre can be a valuable platform for testing new solutions with close correspondence to operational standards of firefighting actions and in relation to other technologies.

Taking into consideration the above-mentioned issues as well as referring to the technology specifics, the use of the Forward Command Centre entails certain operational risks. These risks are related to implementation and deployment in wildfire response. Consequently, the following aspects should be taken into account:

1) as regards training-related preparation and pre-planning activities for wildfire response:
   a) the mass scale of the incident and consequently a number of data sources to be integrated,
   b) complexity of the technosphere of the centre (many tools and solutions to be integrated),
   c) strong dependence on the support of technical staff,
   d) determination of access to telecommunication channels (for example to the Internet, satellite communication tools, radio range),
   e) responsibility still resting with the line commander and limits to the usage of AI,
   f) relatively little confidence in IT decision support systems,
   g) relatively little confidence in AI solutions,
   h) necessity of learning AI algorithms before their practical use,
   i) determination of data (visual data, sensor data, information from the response field),
   j) necessity of ensuring operational self-sufficiency of the centre (access to electricity, equipment, etc.),

k) conditions prevailing in the woods and a wildfire that requires the necessity of adjusting the centre formula to its operation (when the Forward Command Centre is inside of a vehicle or directly in the field);

2) as regards the Forward Command Centre:
   a) stress related to making decisions on the basis of analytical output,
   b) insufficient abilities for self-use of devices by the trainees,
   c) too many solutions to handle simultaneously in which may cause operating difficulties,
   d) stress related to the use of technology (in general),
   e) cognitive overload,
   f) uncertainty of data that feeds algorithms.

The possibility of integrating a number of technologies in the formula of the Forward Command Centre provides both an organisational opportunity and an organisational threat when considering preparation and pre-planning activities in wildfire response. Focusing on the second issue, the increase in the number of solutions intensifies the complexity of the training process. Furthermore, it can be hardly expected that the trainees be familiarised and capable of using all of the technologies deployed in the centre. A good practice to reduce relevant risks is to involve a group of trainees who are in sync and work with each other on a daily basis and/or ensure a group of trainers to serve as technical support during a training course.

4.3.4. Safety issues for deployment of the technology

The use of the Forward Command Centre in training for firefighters relates to a wide spectrum of factors that may have an adverse impact on trainees. This is especially noticeable in case of using the centre in field conditions (for instance on the training field). These factors determine the occupational health and safety conditions of the training course and should be taken into account to ensure the personal safety for firefighters. The following safety factors (hazards, threats) should be highlighted (Rączkowski, 2022):

1) Hazards of moving, loose and protruding parts.
2) Movement of people and equipment.
3) Fall from a height.
4) Electrical shock.
5) Fire-related hazards (thermal radiation, smoke, burn).
6) Microclimate.
7) Severe weather conditions.
8) Noise.
9) Visual radiation.
10) Chemical factors.

11) Biological factors.
12) Mental burden.
13) Dangerous animals.

Table 18 contains results of operationalization of individual factors. They indicate possible circumstances of hazard/threat materialisation during the use of the Forward Command Centre in firefighting training.

Table 18. Examples of circumstances of the materialisation of hazards/threats when using the Forward Command Centre for firefighter training

No.	Hazard	Illustrative circumstances
1	Hazards of moving, loose, and protruding parts	a) Being hit by a drone. b) Being hit by an additional equipment. c) Being hit by a screen. d) Being hit by an environmental element (for example by a branch). e) Tripping over a land unevenness in the woods. f) Tripping over a firefighting hose. g) Stumbling over a computer post. h) Tripping over a cable.
2	Movement of people and equipment	a) Being hit by a robot. b) Being hit by a quad, a fire engine, etc. c) Damage caused by water for fire suppression dropped from the air from an aircraft and/or a helicopter ('Bambi bucket').
3	Fall from a height	a) Fall from a land unevenness while inspecting the field. b) Fall from a vehicle.
4	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to a robot. c) Physical damage to the training infrastructure (a light fixture, an electrical socket).
5	Fire-related hazards (thermal radiation, smoke)	a) Thermal radiation from a fire while operating in the danger zone. b) Smoke contamination while operating in the danger zone or nearby.
6	Microclimate	a) Cold microclimate determined by the weather. b) Hot microclimate determined by the weather.
7	Severe weather conditions	a) Strong wind. b) High temperature on a sunny day. c) Precipitation (heavy rain, snow, etc.). d) Dense fog.
8	Noise	a) Noise caused by firefighting equipment in the field conditions.

Table 18 cont.

No.	Hazard	Illustrative circumstances
9	Visual radiation	a) Solar radiation. b) Radiation from firefighting engines.
10	Chemical factors	a) Chemical substances generated by a robot. b) Chemical substances generated by firefighting engines.
11	Biological factors	a) Biological agents transmitted by other trainees (air ways). b) Biological agents accumulated on training infrastructure and devices.
12	Mental burden	a) Situational stress. b) Inability of using the assessment tool. c) Technical problems with a robot. d) Cognitive overload of a trainee.
13	Dangerous animals	a) Sting by a venomous species. b) Aggressive animals entering the scene.

Source: own study

Respecting good occupational safety and health practices allows working out the following preventive measures to minimise training risks related to the specified hazards/threats:

1) for hazards of moving, loose, sharp and protruding parts:
   a) to fix firmly any devices,
   b) to fix firmly the screens and cables (for example to walls),
   c) to mark safety distances (at least 1 m) around the training platform and other training areas,
   d) to ensure two operators per one device,
   e) to ensure order in the training zone,
   f) to ensure protective shoes for trainees;
2) for movement of people and equipment:
   a) to mark walking paths in the centre,
   b) to order the training zone,
   c) to ensure visibility of engines and other equipment,
   d) to ensure two operators per one device;
3) for fall from a height:
   a) to mark dangerous places on the training field,
   b) to mark dangerous places in the centre,
   c) to plan training activities away from dangerous places on the training field,
   d) to ensure two operators per one device;

4) for electrical shock:
   a) to check electrical devices before every training course,
   b) to devise safety procedures to be able to respond on any physical damage in equipment and infrastructure;
5) for fire-related hazards (thermal radiation, smoke):
   a) to remain in contact with training organisers who know where the fire broke out,
   b) to keep a distance from fire manifestations (flames, smoke),
   c) to ensure and secure the evacuation route and an alternative evacuation route,
   d) to provide personal protection means,
   e) to ensure hermetic infrastructure in the centre;
6) for microclimate:
   a) to wear clothes appropriate to weather conditions,
   b) to ensure beverages appropriate to weather conditions (either hot or cold),
   c) to prepare infrastructure of the centre to operate in different microclimate conditions;
7) for severe weather conditions:
   a) to ensure an umbrella or other means for protection against weather conditions,
   b) to wear clothes appropriate to weather conditions,
   c) to ensure beverages appropriate to weather conditions (either hot or cold),
   d) to prepare infrastructure of the centre to operate in different weather conditions;
8) for noise:
   a) to use earplugs,
   b) to mark safety distances,
   c) to mark/isolate noisy places (if possible),
   d) to organise places for trainees if possible away from noisy places;
9) for visual radiation:
   a) to use personal protection means (for example sunglasses);
10) for chemical factors:
   a) to mark the danger zone and ensure safety distances,
   b) to provide personal protection means,
   c) to ensure technical support team for any maintenance and service activities required on the scene;
11) for biological agents:
   a) to disinfect the training area after every scenario,
   b) to disinfect equipment after its use,

   c) to devise a biological safety manual,
   d) to verify the health condition of every trainee,
   e) to ensure technical workers to be able to selectively use a computer post with a dashboard;

12) for mental burden:
   a) to ensure a friendly atmosphere during a training,
   b) to ensure staff members to support trainees in the technical handling of robots and/or tools to visualise their usage,
   c) to organise a training course with a scenario that is relatively independent of the detection effectiveness (in case of low effectiveness on the use or technical problems with fire detection using robots),
   d) to involve a group of trainees and divide roles and responsibilities in a specific scenario;

13) for dangerous animals:
   a) to protect infrastructure of the centre against unauthorised access,
   b) to ensure first aid equipment (including antidotes), procedures and medical staff for trainees affected by dangerous animals.

The preparation and direct use of the Forward Command Centre in firefighter training is a complex venture. And the complexity entails also personal risks for trainees, trainers and support staff members. There may be different levels of the risks' awareness, especially when a training course is organised in a field setting. This is why a safety briefing could be required to ensure common understanding of the situational picture (with respect to a training course) and becoming familiarised with safety measures. As the Forward Command Centre is the place for co-work of action staff members, it is good practice to indicate a safety officer to monitor safety issues during each training course and to be ready to help trainees in the case of an emergency.

4.4. MESH-in-the-Sky

4.4.1. Technology in a nutshell

Effective communication is the core issue that determines the success of wildfire response. It becomes quite challenging in difficult conditions prevailing in the woods, where terrain unevenness or depressions, trees, rocks and other obstacles may impede information exchange between responders. Firefighters may experience various hindering factors such as a limited range of radio waves and GSM, a high cost of satellite communication, communication shielding or cross-polarisation effects (Popov, 2019). From the practical point of view, classical communication means and methods are also limited due to long distances between senders and receivers, and signal loss on the cables. Consequently, firefighters are constantly looking for new ideas to improve communication possibilities communication capabilities, as this is essential to responding effectively to a fire and ensuring the personal safety of all those involved in the firefighting operation. Some of the solutions are benchmarked in technological applications in the disaster and military environment (Chand et al., 2018). A mesh network is very promising, allowing flexible information flow using modern wireless technologies (Paulon et al., 2022; Penmatsa et al., 2024). It can play a significant role of a promising information system for emergency management, disaster management and crisis management (Ristvej, Zagorecki, 2011).

MESH-in-the-Sky is a kind of a mesh network technology (comprised by a set of connected elements that commonly assure enhanced communication ability). As regards the SILVANUS project, it was "designed to establish robust wireless communication for first responders during critical fire operations in the woods. This advanced system utilizes Software Defined Radio (SDR) technology to overcome environmental challenges such as signal interference from vegetation and terrain. The network facilitates real-time data transmission between ground-based command centres and the SILVANUS cloud command centre, enabling strategic coordination and efficient response during the crucial "Golden Hour" of emergencies" (SILVANUS, 2024). This idea is illustrated in Figure 38.

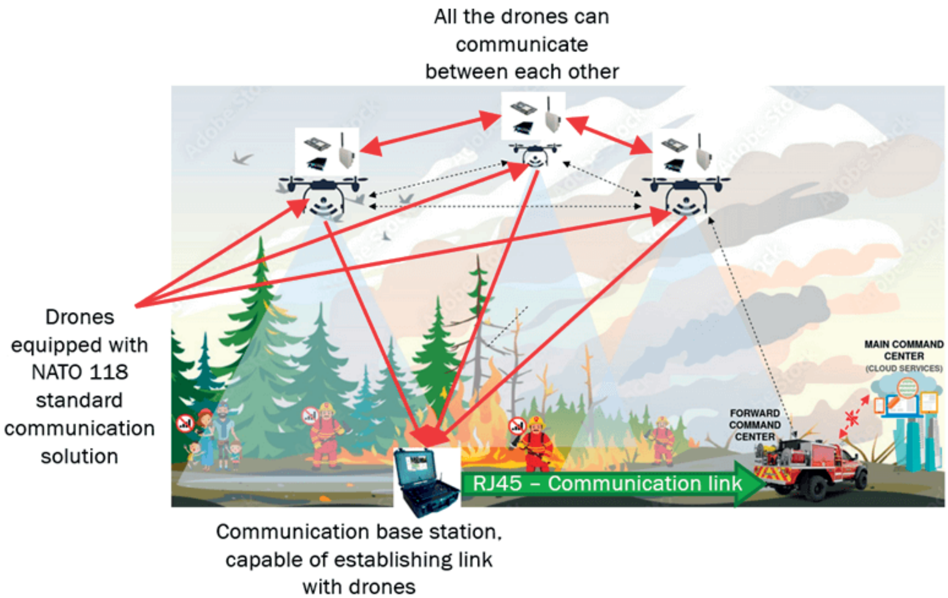

Figure 38. General idea of MESH-in-the-Sky
Source: (SILVANUS, 2024)

This idea reflects the fact that MESH-in-the-Sky meets operational requirements of firefighters to provide access to resources and means of communication in the forest. The technology enables covering the wildfire scene by wireless solutions for data collection, information analyses, shaping the situational picture, and obtaining support of decision making systems. Drones are used as transmitters for data flows. The flows exist between all essential elements of the communication structure, namely communication base stations, Forward Command Centres and the main command centre. From this viewpoint a swarm of drones may constitute a wireless communication network for response purposes. Consequently, potential beneficiaries of the solution are line firefighters, commanders as well as staff members of command centres, emergency management centres, disaster management centres and crisis management centres. Other safety entities may be connected to the communication network as well, so the potential spectrum of users is wider.

The main functionality of MESH-in-the-Sky is to ensure wireless communication possibilities for entities involved in wildfire response despite of terrain constraints. It provides a robust communication network, particularly if the existing infrastructure is deficient. This covers the following potential benefits (SILVANUS, 2024):

a) live surveillance on the basis of integrated cameras,
b) data transmission to a remote command centre via cloud technology,
c) network hotspots for personnel connectivity provided by ground nodes,
d) ensuring continuous communication by using of MESH radios to operate beyond the line of sight,
e) exchanging information from the field to the cloud for comprehensive data management (including data analysis).

The benefits may be transposed to operational functionalities expected by firefighters to meet their practical needs (i.a.):

a) ensuring acceptable quality of information flows between commanders and line firefighters in the woods,
b) transferring information about a wildfire directly from the response scene to command centres (forward command centre and main command centre),
c) ensuring access to computational and decision support functionalities when GSM, radio and satellite communication connections are broken,
d) possibility to dynamically shape communication possibilities in difficult terrain conditions or hard-to-reach places,
e) deploying drones which may be additionally equipped with cameras, detectors, etc.,
f) possibility of enabling permanent monitoring of the health condition of firefighters that participate in the firefighting action.

It should be emphasized that MESH technologies are being developed and this facilitates the implementation of MESH-in-the-Sky. The edge elements are accessible on the market and specific software may be tailored to current expectations of end-users. The technology maturity level is high enough for wide deployment directly on the wildfire response scene. MESH-in-the-Sky is a good example on how to organise the communication and data flows despite of impeding factors during the response. It may be checked, learnt and evaluated during training for firefighters with a positive effect on preparation and pre-planning activities in wildfire response.

4.4.2. Operational protocol

Information is a crucial resource when fighting a fire in the woods. As an effect, MESH technologies may be applied in the process of wildfire response. The way of their application can be understood as operational protocol for the use of the technology for training purposes. This applies also to MESH-in-the-Sky. Figure 39 presents the role of the use of MESH-in-the-Sky in support of wildfire response training.

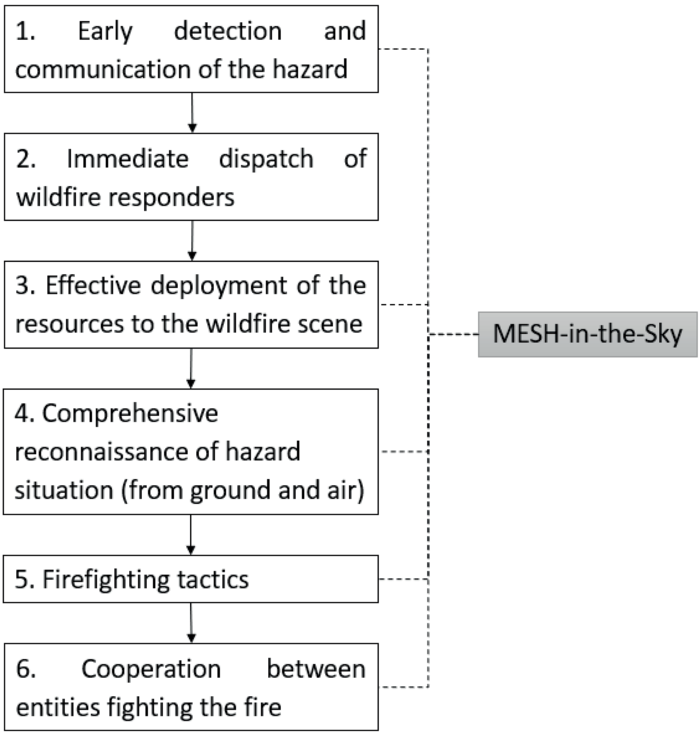

Figure 39. Role of MESH-in-the-Sky in support of wildfire response training

Source: own study

It should be borne in mind that the technology is applicable to nearly all phases of the response. Those phases comprise early detection and communication of the hazard, effective deployment of resources to the wildfire scene, comprehensive reconnaissance of hazard situation (from the ground and from the air), firefighting tactics and cooperation between firefighting entities. This underpins the fact that uninterrupted information flows are very important for firefighters and other responders to be sure what to do in different moments of fighting a fire in the woods. The next issue is that MESH-in-the-Sky can cover almost the entire spectrum of training scenarios. Table 19 presents a set of examples on how to apply MESH technology to training activities for particular response phases. The list operationalises the reference protocol of the technology use for firefighting training purposes.

Table 19. Examples on how to apply MESH-in-the-Sky to particular phases of wildfire response

No.	Phase	Examples
1	1. Early detection and communication of the hazard	1) Trainee uses MESH-in-the-Sky to connect to detectors (IoT) to verify information about hotspots from social sensing solutions (for example the X platform). 2) Trainee connects to field firefighters to issue orders concerning verification of positives reported by field sensors (for example IoT). 3) Trainee establishes a communication channel with field firefighters and alert them of a location of a hotspot. 4) Trainee communicates a hazard to command posts and information centres of other safety entities (for instance to the forest service dispatching point, an emergency centre).
2	3. Effective deployment of the resources to the wildfire scene	1) Trainee informs drivers in firefighting vehicles about safe arrival routes to the wildfire scene. 2) Trainee shares information with drivers in firefighting vehicles about factors that impede effective getting to the wildfire scene.
3	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee collects information about the hazard situation from zones where communication obstacles exist. 2) Trainee dispatches drones to extend the range of communication equipment on the field, and verifies the new range. 3) Trainee dispatches robots to extend the range of communication equipment on the field, and verifies the new range.
4	5. Firefighting tactics	1) Trainee monitors the range of communication equipment in the danger zone for planning of firefighting tactics.

No.	Phase	Examples
		2) Trainee ensures proper coverage of communication zone to proceed effectively with firefighting. 3) Trainee plans the use of drones to ensure both effective communication zone and support for other response activities (for example fire detection or water drop for fire suppression from the air executed by a swarm of drones). 4) Trainee adjusts the use of drones to the schedule of water drops for fire suppression from the air carried out by planes, helicopters and a swarm of (other) drones.
5	6. Cooperation between firefighting entities	1) Trainee shares information about a hazard among all end-users. 2) Trainee includes additional entities (for instance the armed forces) to the MESH communication network. 3) Trainee monitors access to information channels of all entities involved to the response.

Source: own study

Application of MESH-in-the-Sky and other MESH technologies to the training for firefighters to prepare them for wildfire response should reflect the general training procedure. Particular attention should be paid to the technical preparation of the tool as firefighters are focused on specific functionalities rather than on the technical issues. This concerns especially field firefighters and commanders who do not have time for advanced maintenance and typically technical activities during wildfire response. As far as the training is concerned, the following activities need to be taken into account:

1) Deployment of MESH communication nodes accordingly to the number and specifics of training actors.
2) Establishment of the MESH network.
3) Integration of MESH communication nodes in the MESH network.
4) Field verification of the MESH network.
5) Familiarisation with the training scenario.
6) Pre-training use of MESH-in-the-Sky (elements of training scenario) to become familiarised with functionalities and areas of its use when responding to a wildfire.
7) Essential use of MESH-in-the-Sky to conduct a training scenario (directly by a trainee or indirectly with the support of a trainer).
8) Debriefing after the training and training evaluation.

The use of MESH-in-the-Sky requires complex and comprehensive preparation of the training technosphere. First activities are for the technical support staff and/or technology providers to prepare effective communication environment of the response. From the practical viewpoint, firefighters are action-oriented and technical handling should be kept to the necessary minimum. On the other hand, the flexible formula of MESH-in-the-Sky allows adjusting it to a wide spectrum of communication scenarios. It is reflected in the operational protocol and may face different operational expectations of firefighters.

4.4.3. Enhancement capabilities

MESH technologies have a dual-nature. They combine hardware and software in a unique way to achieve common communication objectives. In terms of the importance of communication, this offers valuable opportunities for improvement. First of all, MESH technologies can be adjusted to real operational needs and expectations of firefighters and other actors of wildfire response. Secondly, the technology development may give rise to new ideas concerning the use of specific solutions (including MESH-in-the-Sky). In general, testing MESH technologies in a real firefighting action is challenging and can be impeded by legal constrains (for example a ban on flights over the woods during the action). However, the training conditions provide adequate opportunities, which has a positive effect on familiarising firefighters with new technologies. Consequently, the use of MESH-in-the-Sky in training for firefighters to prepare them to wildfire response may generate two-site synergistic effect.

Focusing on training-related preparation and pre-planning activities for wildfire response, the application of MESH technologies (including MESH-in-the-Sky) allows achieving enhancement by (i.a.):

a) increasing the speed of command transmission,
b) lowering vulnerability to communication obstacles,
c) increasing the range of communication on the field,
d) prompt reporting of secondary hazards,
e) improving situational awareness among firefighters,
f) reliable informational connection between the field and command centres,
g) shortening the time for confirmation of the hazard occurrence from multiple sources of information,
h) decreasing operational risks related to cooperation between different entities (including the fire service),
i) allowing the execution of immediate warning activities,
j) making communication between entities more effective,
k) better understanding of wildfire conditions.

The central category of enhancement of training-related preparation and pre-planning activities for wildfire response is enhancing effective communication between actors of the firefighting action. The rest of benefits seem to be secondary ones. MESH technologies may constitute a valuable communication layer of the response organisation. It may replenish (recommended) or even replace (not recommended) traditional communication means and methods (for example radio communication devices, satellite communication equipment, GSM tools). It can prove to be especially valuable in difficult terrain conditions, where physical communication obstacles are visible.

As it comes to the point of view of technology, application of MESH technologies in preparation and pre-planning activities for wildfire response (placing special attention on training for firefighters) can help in seeking improvements by:

a) new kinds of communication nodes integrated,
b) new kinds of communication standards used,
c) tightened integration of communication technologies,
d) more effective platform for communication integration,
e) more effective communication flows,
f) new organisational structures for deployment of MESH technologies,
g) new technical details to be reflected on the basis of expectations of wildfire responders,
h) new algorithms for drones operating on the field.

Technological improvements related to MESH technologies (including MESH-in-the-Sky) should focus on communication network itself and the network elements. It is important to follow the development of emergency communication standards to face current operational challenges and to make the solutions tailored to firefighters' needs. From the practical point of view, it could be valuable to integrate the MESH to classical communication means and methods. Digitalisation of radio communication, GSM communication and satellite communication may facilitate this process, just like a flexible organisational formula of the MESH.

The technological specifics and potential enhancement benefits are great advantages of implementing MESH technologies. However, the implementation entails certain operational risks and operational threats should be considered in the analysed context. The following aspects need to be taken into account:

1) as regards training-related preparation and pre-planning activities for wildfire response:
   a) mass scale of the incident and consequently a number of communication nodes to integrate,
   b) complexity of the communication technosphere (many different communication standards to be integrated),
   c) complexity of the communication technosphere (many different tools and solutions to be learned by trainees),
   d) strong dependence on technical staff support,
   e) relatively little confidence for Wi-Fi solutions in the woods,
   f) necessity to ad hoc shaping of communication conditions,
2) as regards MESH technologies:
   a) stress related to trust in new solutions,

b) low self-maintenance skills of trainees when something goes technically wrong,
c) stress related to the use of technology (in general),
d) cognitive overload.

The profile of operational threats suggests that some of them may be handled thanks to completing a training course. At the highest level of probability firefighters who have already used MESH technology on the training field would be more familiar with it and able to use it during real wildfire response action. The rest of the threats are related to technical maintenance and support. Consequently, it is hard to imagine training for firefighters without the help from technology providers. In general, close cooperation between technology providers and technology users seems to be crucial to exploit opportunities for improvementenhancement capabilities when talking about MESH-in-the-Sky and other MESH technologies.

4.4.4. Safety issues for deployment of the technology

The use of MESH technologies in training for firefighters relates to some factors with potentially adverse impact on the trainees' health. These factors determine occupational health and safety conditions of a training course. Training organisers and technology providers should take them into account when implementing the technology in educational and real action circumstances. The following technology-related safety factors (hazards, threats) should be taken into account (Rączkowski, 2022):

1) Hazards of moving, loose and protruding parts.
2) Movement of people and equipment.
3) Fall from a height.
4) Electrical shock.
5) Fire-related hazards (thermal radiation, smoke, burn).
6) Microclimate.
7) Severe weather conditions.
8) Noise.
9) Visual radiation.
10) Chemical factors.
11) Biological factors.
12) Mental burden.
13) Dangerous animals.

Because some MESH solutions (and especially MESH-in-the-Sky) require deploying drones, the set of occupational hazards and threats is very close to that related to drones. It is operationalised in Table 20 with specific examples. They mean possible conditions of hazard/threat materialisation during the use of MESH technologies in firefighting training. As the technology is dedicated to field conditions, it is reflected in the examples of potential circumstances in the table.

Table 20. Examples of potential circumstances of materialisation of hazards/threats when using MESH-in-the-Sky during training for firefighters

No.	Hazard	Illustrative circumstances
1	Hazards of moving and loose, and protruding parts	a) Being hit by a drone. b) Being hit by a screen. c) Being hit by a transmitter from a drone. d) Being hit by an environmental element (for example by a branch). e) Stumbling on uneven ground in the forest. f) Tripping over a firefighting hose. g) Stumbling on a computer post. h) Tripping over a cable a cable.
2	Movement of people and equipment	a) Being hit by a quad, a fire engine, etc. b) Collision with an aircraft and/or a helicopter. c) Damage caused by water drop for fire suppression from the air from an aircraft and/or a helicopter ('Bambi bucket').
3	Fall from a height	a) Fall from a cliff, sinkhole or other type of unevenness of the terrain while using a drone.
4	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to the training infrastructure (a light fixture, an electrical socket).
5	Fire-related hazards (thermal radiation, smoke)	a) Thermal radiation from a fire while operating in the danger zone. b) Smoke contamination while operating in the danger zone.
6	Microclimate	a) Cold microclimate determined by weather.
7	Severe weather conditions	a) Strong wind. b) High temperature on a sunny day. c) Precipitation (heavy rain, snow, etc.). d) Dense fog.
8	Noise	a) Noise caused by firefighting equipment in field conditions.
9	Visual radiation	a) Solar radiation. b) Radiation from firefighting engines.
10	Chemical factors	a) Chemical substances generated by firefighting engines.
11	Biological factors	a) Biological agents transmitted by other trainees (air ways). b) Biological agents accumulated on training infrastructure and devices.

Table 20 cont.

No.	Hazard	Illustrative circumstances
12	Mental burden	a) Situational stress. b) Inability of using the assessment tool. c) Technical problems with a drone. d) No access or only a limited one to communication channel. e) Occurrence of physical communication constraints.
13	Dangerous animals	a) Bite from a venomous animal. b) Being hit by an animal stressed by a drone or by communication equipment.

Source: own study

The good occupational safety and health practices refer to the means and ways of effectively confronting training risks. They are specified below:

1) for hazards of moving, loose, sharp and protruding parts:
   a) to fix firmly the screens and cables (for example to walls),
   b) to fix firmly drone devices (including sensors and transmitters),
   c) to mark safety distances (at least 1 m) around the training platform and other training areas,
   d) to ensure order in the training zone,
   e) to ensure protective shoes and helmets for trainees;
2) for movement of people and equipment:
   a) signposting of walking paths in the operations centre,
   b) to order the training zone,
   c) to ensure visibility of engines and other equipment,
   d) to use voice and light signals when firefighting engines are operating;
3) for fall from a height:
   a) to mark dangerous places on the training field,
   b) to plan training activities far away from dangerous places on the training field,
   c) to secure cliffs, sinkholes and other land unevenness that are close to the training posts;
4) for electrical shock:
   a) to check electrical devices before every training course,
   b) to devise safety procedures to respond to any physical damage to equipment and infrastructure;
5) for fire-related hazards (thermal radiation, smoke):
   a) to stay in contact with training organisers who know where the fire has started,

   b) to keep a distance from fire manifestations (flames, smoke),
   c) to ensure and secure the evacuation route and an alternative evacuation route;
6) for microclimate:
   a) to wear clothes appropriate to weather conditions,
   b) to ensure beverages appropriate to weather conditions (either hot or cold);
7) for severe weather conditions:
   a) to ensure an umbrella or other means for weather protection,
   b) to wear clothes appropriate to weather conditions,
   c) to ensure beverages appropriate to weather conditions (either hot or cold);
8) for noise:
   a) to use earplugs,
   b) to mark safety distances,
   c) to mark/isolate noisy places (if possible),
   d) to organise places for trainees possibly far away from noisy places;
9) for visual radiation:
   a) to use personal protection means (for example sunglasses);
10) for chemical factors:
   a) to mark containers for chemical substances,
   b) to mark the danger zone and ensure safety distances;
11) for biological agents:
   a) to disinfect the training area after every scenario,
   b) to disinfect equipment after its use,
   c) to devise the biological safety manual,
   d) to verify the health condition of every trainee,
   e) to ensure a technical worker to be able to selectively use a computer post with a dashboard;
12) for mental burden:
   a) to ensure a friendly atmosphere during a training course,
   b) to ensure staff members to support trainees in the technical use of drones and/or tools to visualise their usage;
13) for dangerous animals:
   a) to ensure first aid equipment (including antidotes), procedures and medical staff for trainees affected by dangerous animals.

MESH technologies are not independent of other elements of the training technosphere. For this reason the catalogue of hazards and threats is relatively complex. However, close correspondence with safety and security measures related to other technologies give rise to possibilities of planning and applying integrated solutions aimed at risk' minimisation in an integrated way. As technological support is crucial in the analysed context, the good solution could be to appoint a technical support team for needs of the training. Direct subordination to a safety officer would simplify and enhance the effectiveness of mutual efforts in lowering situational stress and mental burden, also with a positive influence on abilities to avoid materialisation of other hazards and threats.

Chapter 5

Enhancement of preparation and pre-planning activities for wildfire response with the use of decision support systems for firefighter training

5.1. Multilingual Forest Fire Alert System (DSS-MFAS)

5.1.1. Technology in a nutshell

Decision support systems (DSS) are commonly analysed in relation to disaster management. For example, they have been used in disaster logistics related to mass evacuation of people (Hadiguna et al., 2014), identifying strategic roads in disaster situations (Ghavami, 2019), and enhancing community resilience by prioritizing stakeholder interactions (Elkady et al., 2024). Generally speaking, their use in the context analysed allows making optimisations, spatial modelling, multicriteria decision analysis, simulations, deploying the graph theory, text mining, and combined modelling (Elkady et al., 2024). DSS serve also for analyses and to confirm alerts in wildfire warning systems with respect to the implementation of machine learning frameworks (Bhowmik et al. 2023), especially that this may facilitate assisting people in escape wildfires (Kamilaris et al., 2023), and support fire services to put out a fire.

Data fusion is a way of developing the analysis potential of DSS to make sure that a fire has really occurred in the given area. The Multilingual Forest Fire Alert System (DSS-MFAS) was designed to use this technology in the practice of firefighting in the woods (SILVANUS, 2024). Its general concept is illustrated in Figure 40.

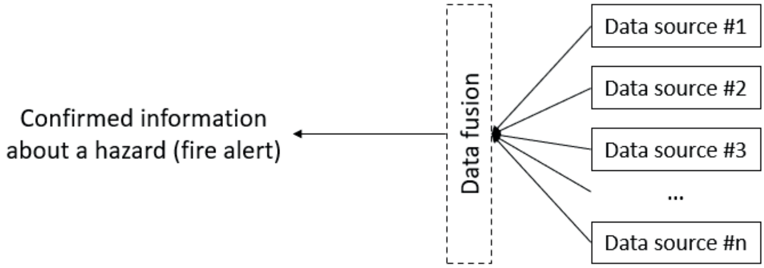

Figure 40. General concept of data fusion implementation to DRR to analyse and confirm fire alerts

Source: own compilation

Data fusion relies on connecting multiple data from different data sources to compare them and/or their elements, to analyse and to confirm information about a hazard (fire alert). From this point on it is valuable tool for everyone who needs to know whether and where a hazard exists. Consequently, potential beneficiaries of this technology are operators of dispatching points, warning points of fire service and forest service, command centres (main command centres and the forward ones), emergency management centres, disaster management centres, and crisis management centres. Application of data fusion gives a better opportunity of making the correct decision to initiate wildfire response on the basis of high probability alert. This is very important during the fire season as numerous hot spots may occur at the same time and rational distribution of limited resources of firefighters is crucial to handle in a hazard situation.

The main functionality of DSS-MFAS is to ensure high probability information about a fire on the basis of data fusion linked to multiple data sources in the given area. The detection provides decisions on the notification of fire incidents using the multilingual textual framework. This applies to the following potential benefits (SILVANUS, 2024):

a) alerting of fire incidents,
b) detecting the fire location,
c) identifying the probability of fire event location based on data fusion.

It should be emphasized that the technology of data fusion is open for multilingual analysis of data. This means a possibility of considering different languages of data and information.

The benefits may be transferred to operational functionalities that are expected by firefighters to meet their practical needs (i.a.):

a) automatically analysing different data sources during fire monitoring of a wide area,
b) indicating locations of potential hotspots,
c) calculating the probability of hotspot occurrence,

d) ensuring an acceptable quality of information about a fire,
e) transferring information about hotspots directly from the response scene to command centres (forward command centre and main command centre) and *vice versa*,
f) providing input to calculation models for fire risk assessment where probability is one of the core risk indicators,
g) possibility of integrating to fire spread forecast solutions (input data about places of hazard materialisation –places from where the hazard spreads),
h) providing input to another DSS by information about location of hot spots and their probability,
i) indicating areas where additional firefighting resources should be deployed,
j) possibility of integration to IT dashboard,
k) possibility of integration to GIS solutions and then for visualisation of hot spots on a map,
l) technological openness for connecting to different sources of fire data.

Data fusion is quite frequently used when analysing different sources of data and information (EU-SENSE, 2022; EU-RADION, 2023). In the context of early and reliable warning about a fire in the woods, it may involve data and information from, for example, IoT devices, reports from firefighters, reports from forest service, data collected by robots and drones, and massages generated in the social media (for instance in citizen engagement applications).

5.1.2. Operational protocol

The universal process of wildfire response can play the role of a cognitive structure for implementing DSS-MFAS (and other data fusion solutions with similar functionalities) to firefighter training. The training can be expanded with analytical mechanisms related to particular phases of the response. This has been presented in Figure 41.

DSS-MFAS is capable of supporting training activities referring to almost all wildfire response phases. They are early detection and communication of the hazard, effective deployment of resources to the wildfire scene, comprehensive reconnaissance of hazard situation (from the ground and from the air), firefighting tactics, and cooperation between firefighting entities. In all these cases reliable or even probability-determined information about location of hotspots in the woods may help firefighters to make proper and quick decisions on where and how to respond. These issues may be learnt by firefighters with the use of DSS-MFAS as well. Examples on how to implement DSS-MFAS in training activities with respect to particular response phases are listed in Table 21.

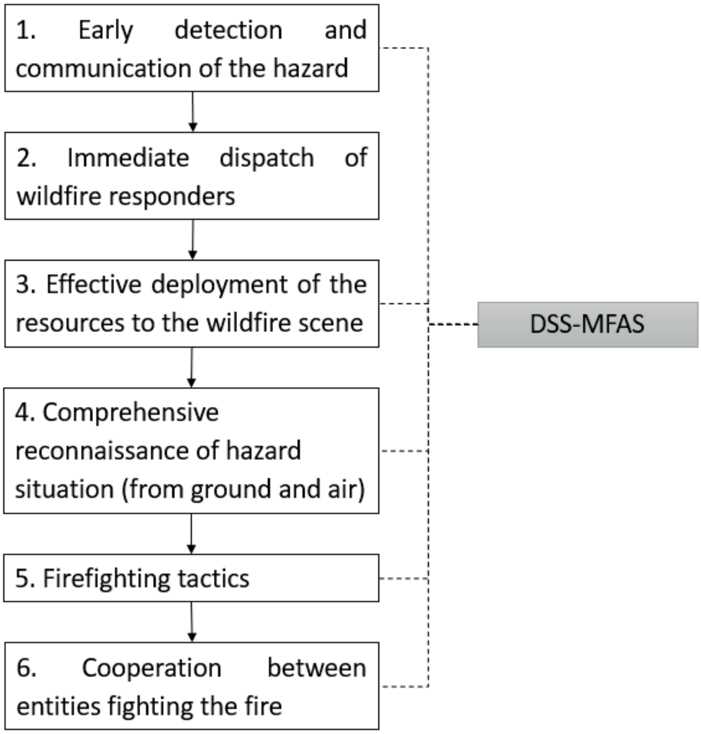

Figure 41. Role of DSS-MFAS in support of wildfire response training

Source: own study

Table 21. Examples on how to implement DSS-MFAS into particular phases of wildfire response

No.	Phase	Examples
1	1. Early detection and communication of the hazard	1) Trainee confirms the detection of a hazard based on different sources of information. 2) Trainee checks the probability of hazard occurrence in given hotspots. 3) Trainee verifies the reliability of the alert. 4) Trainee marks a preliminary zone where a wildfire has occurred.
2	3. Effective deployment of the resources to the wildfire scene	1) Trainee adjusts the arrival route to the wildfire scene as regards with respect to the location of the most probable hotspots. 2) Trainee seeks alternative directions and arrival routes in case the wildfire develops as reflected by location of the most probable hotspots.

No.	Phase	Examples
3	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee monitors the wildfire scene from the general ground perspective to collect basic reconnaissance information about the location of hotspots.
4	5. Firefighting tactics	1) Trainee determines the general firefighting tactics on the basis of information about the most probable hotspots. 2) Trainee considers the less probable hotspots in planning general firefighting tactics to ensure operational continuity. 3) Trainee marks the danger zone for further planning of firefighting tactics.
5	6. Cooperation between firefighting entities	1) Trainee verifies the need to support firefighters by other entities when the number of hotspots is too high to be covered by the fire service on its own. 2) Trainee dispatches supporting entities (for example forest service) to verify hotspots characterised by less probability.

Source: own study

The use of DSS-MFAS in wildfire response training bases on the following general operational activities:

1) Technical connection of DSS-MFAS to different data sources.
2) Functional integration of DSS-MFAS to different data sources.
3) Field verification of alert correctness.
4) Familiarisation with the training scenario.
5) Pre-training use of DSS-FMAS (elements of the training scenario) to become familiarised with functionalities and areas of its use when responding to a wildfire.
6) Essential use of DSS-FMAS to carry out a training scenario (directly by a trainee or indirectly with the support of a trainer).
7) Debriefing after the training and training evaluation.

Deployment of DSS-MFAS (and other data fusion solutions) to firefighter training is strongly functionally determined. This means that a trainee is focused on functionalities that the technology ensures. The technical activities related to the training should be executed by the technical support staff. This is also necessary in the case of data source integrated to the analysed technology. There is a need of analysing whether results of data fusion should be transmitted to field firefighters. It is reasonable from the perspective of firefighting effectiveness. Firefighters would be well-informed about the total number of hotspots to put out and their precise location. Training for firefighters could be advantageous in this case as it may verify the tool in practice and by practitioners.

5.1.3. Enhancement capabilities

Data fusion is an intangible way of transferring data from the field to decision makers responding to a wildfire. It uniquely combines the real phenomena of fires with semi-realistic decision-making processes. The automation of these processes is an additional advantage when talking about DSS-MFAS. The connection indicates two groups of enhancement capabilities. They are the possibilities for preparation and pre-planning activities in wildfire response and the possibilities that involve technology development (in close relation to expectations of end-users).

Focusing on training-related preparation and pre-planning activities for wildfire response, the application of DSS-MFAS (and other data fusion technologies) allows achieving enhancement by (i.a.):

a) reducing the time to confirm the occurrence of a hazard from multiple sources of information,
b) prompt reporting of hotspots occurrence,
c) undertaking immediate warning activities,
d) increasing the reliability of fire alerts,
e) indicating the precise location of hotspots,
f) improving situational awareness among firefighters, decision makers and other wildfire responders,
g) minimising operational risks related to fire notification and reporting,
h) reducing operational risks related to incorrect decisions on where to initiate a firefighting action,
i) better understanding of wildfire conditions.

The central category of enhancing training-related preparation and pre-planning activities for wildfire response is to ensure that decision makers are convinced that decisions made by them reflect real wildfire conditions and do not base on false positives. This shapes the rationality of wildfire response and allows saving firefighting resources (resources are often limited and there is a need of dispatching them to places where firefighters are the most needed). In addition, the strong influence on operational risks is also noticeable. Minimising the risk of making wrong or non-optimal decisions seems to be the most important enhancement direction.

As regards to the technology point of view, application of DSS-MFAS to preparation and pre-planning activities for wildfire response (with particular attention on firefighter training) may help seek improvements by:

a) new kinds of data sources integrated,
b) new kinds of data transfer standards used,

c) enhancing the integration of detection technologies,
d) enhance the integration of communication technologies,
e) making the platform for integration of detection tools more effective,
f) new DSS modules to assess wildfire risk (as probability is one of the core risk factors and may be supplemented by, for example, the factor of consequences),
g) new algorithms for data collection for the purposes of fire alerting.

Technology improvements related to DSS-MFAS (and other data fusion solutions with similar functionalities) should focus on improving the reliability of fire alerts and probability of fire reports. Firstly, data fusion algorithms need to be as effective as possible to reflect the likelihood that the hazard would occur. It is especially important when considering real events (with probability of '1' or '100%', i.e. the certain ones). Secondly, data fusion technology may require improvements from integrated detection technologies. Both of these two ways of enhancement should be implemented to deliver solutions tailored to firefighters' expectations and operational needs.

As enhancement capabilities are related to technological issues and specifics of wildfire response, some operational risks and operational threats should be considered in the analysed context. The following aspects need to taken into account:

1) as regards training-related preparation and pre-planning activities for wildfire response:
   a) mass scale of the incident and consequently a number detection nodes to be integrated,
   b) complexity of data fusion algorithms,
   c) different data transfer standards to be considered,
   d) strong dependence on technical staff support,
   e) relatively little confidence to DSS solutions in conditions prevailing in the woods,
   f) low cognitive value without visualisation of data fusion results (location of hotspots on a map);
2) as regards DSS-MFAS technologies:
   a) stress related to trust in new solutions,
   b) low self-maintenance skills of devices by trainees when something goes technically wrong,
   c) stress related to the use of technology (in general),
   d) cognitive overload,
   e) risk related to basing on probabilities when making decisions.

Some of operational threats may be handled with the use of the training for technology users (firefighters). The more time is spent using the tool, the greater the confidence during real firefighting action in the woods. Furthermore, DSS-

MFAS is a kind of solution that requires technical support. The support should involve preparation of the training environment and interpretation of data fusion results. Following these ways may additionally increase enhancement capabilities, especially at the beginning of technology implementation.

5.1.4. Safety issues for deployment of the technology

Deployment of DSS-MFAS involves a semi-direct contact between the training field and the trainees. It means that training attendee is connected to the wildfire scene with the use of technological means (generally via such visualisation equipment as a screen). This determines specific but fortunately rather limited kinds of hazards. From the viewpoint of trainees, the following factors should be analysed (Rączkowski, 2022):

1) Hazards associated with the movement of people.
2) Electrical shock.
3) Visual radiation.
4) Biological factors.
5) Mental burden.

The circumstances of hazard materialisation are given in Table 22.

Table 22. Examples of circumstances of the materialisation of hazards when using DSS-MFAS to train firefighters

No.	Hazard	Examples of circumstances
1	Hazards of moving and loose, and protruding parts	a) Being hit by a screen. b) Stumbling over a computer post. c) Tripping over a cable.
2	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to the training infrastructure (a light fixture, an electrical socket).
3	Visual radiation	a) Radiation generated by screens.
4	Biological factors	a) Biological agents transmitted by other trainees (air ways). b) Biological agents accumulated on the training infrastructure.
5	Mental burden	a) Situational stress. b) . Strenuous competition c) Too many sources of information (information overload). d) Inability of using the tool. e) Mental risk related to making decisions on the basis of probability factors.

Source: own study

On the basis of occupational safety and health standards, reference prevention measures are suggested to minimise training risks related to the specified hazards:

1) for hazards of moving, loose, sharp and protruding parts:
   a) to firmly fix the screens and cables (for example to walls),
   b) to mark safety distances (at least 1 m) around the training platform and other training areas,
   c) to ensure order in the training zone,
2) for electrical shock:
   a) to check electrical devices before every training session,
   b) to devise safety procedures to respond on any physical damage to equipment and infrastructure,
3) for visual radiation:
   a) to ensure proper illumination in the training room,
4) for biological agents:
   a) to disinfect the training area after every scenario,
   b) to disinfect equipment after its use,
   c) to devise a biological safety manual,
   d) to verify the health condition of every trainee,
5) for mental burden:
   a) to minimise or eliminate competition elements from the training scenario,
   b) to ensure a friendly atmosphere during a training course,
   c) to ensure staff members to support trainees in the technical use of the assessment tool (including support in proper interpretation of the assessment results).

The relatively low level of occupational risk is associated with the deployment of DSS-MFAS into training for firefighters. It typically resembles an office job (even if it takes place in field conditions). It comes down to making visual analyses of data fusion results, interpreting them, and making probability-informed decisions. It is worth highlighting that the hazard notification is generally automated. It depends on integration to detection tools and does not rely on a trainee. Integration to GIS may help shape the situational awareness of the wildfire picture and access to the technical support team should significantly minimise the mental burden risks.

5.2. Resource Allocation of Response Teams (DSS-RART)

5.2.1. Technology in a nutshell

The allocation of wildfire resources is a challenging issue when executing preparation and pre-planning activities in wildfire response (Avci et al., 2024). The challenging nature of the issue stems from the complexity of wildfire response, limited amount of wildfire responsers, and dynamism of the hazard development. Consequently, the multi-agency coordination resource allocation and routing decision-making problem gains in importance (Momeni et al., 2023), and spatial modelling is carried out for resources allocation and resident evacuation (Zhou, Erdogan, 2019). Nevertheless, the resource allocation of response teams remains an essential problem for planners and commanders on the field. It may be solved with the use of modern technologies. The Decision Support System on Resource Allocation of Response Teams (DSS-RART) is a relevant example.

The main objective of DSS-RART "(...) is to assist commanders take optimal decisions regarding the resource allocation of response teams in the field depending on the evolution of a wildfire incident and the status of the available response teams. For instance, it may suggest assigning additional teams to a specific area that is at high-risk" (SILVANUS, 2024). The tool considers fire detection results, initial unit distribution, fire spread projection, distribution of the population in the danger zone and GIS data. The optimisation process bases on "(...) mathematical model developed for management of wildfires with the objective, first to minimize the number of people that may be exposed to risk (and above all life loss) in the high-risk areas and second, to minimize the total cost of fire containment and property losses. The model optimizes the resource allocation decisions given limited capacity and availability while considering the fire spread model and the population distribution" (SILVANUS D5.3, 2023). Resource Allocation Diagram is illustrated in Figure 42.

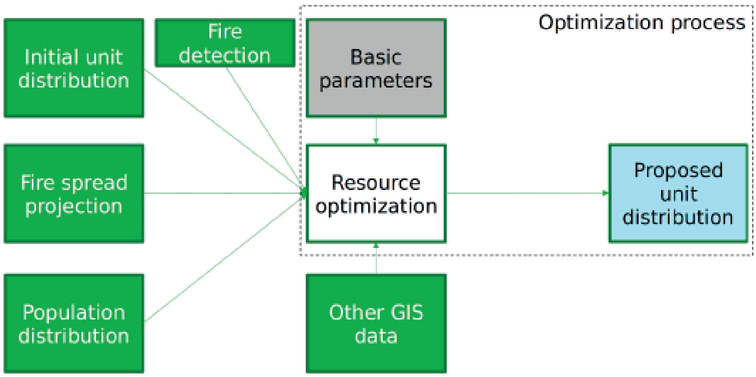

Figure 42. Resource Allocation Diagram in DSS-RART
Source: (SILVANUS D5.3, 2023)

Data that feeds DSS-RART can be gathered and presented on four essential kinds of layers presented in Figure 43.

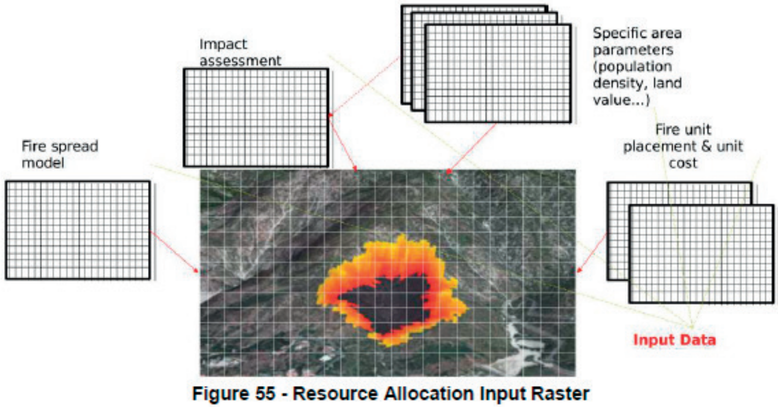

Figure 43. Data layers in DSS-RART
Source: (SILVANUS D5.3, 2023)

Results of the use of DSS-RART are presented in Figure 44.

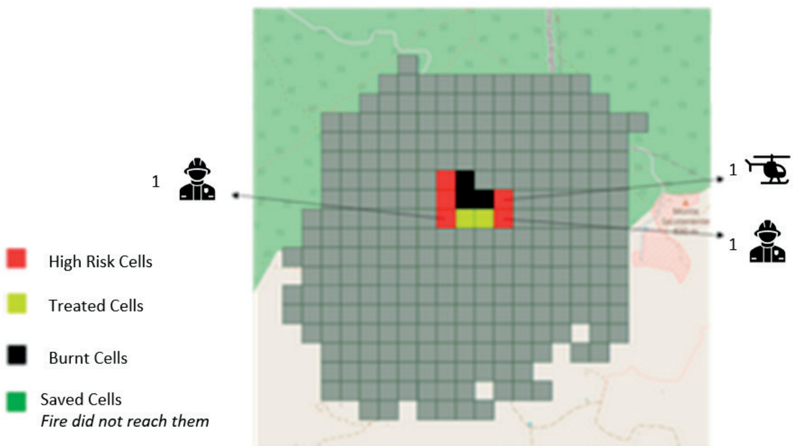

Figure 44. Results of the use of DSS-RART
Source: (SILVANUS, 2024)

Potential beneficiaries of the tool are wildfire response planners (in dispatching posts, command centres, emergency management centres, disaster management centres, crisis management centres), and commanders who decide on the allocation of response teams on the firefighting scene in the woods. DSS-RART can be additionally used by field commanders and other field firefighters to analyse firefighting priorities and to ensure personal safety of the responders.

The main DSS-RART functionality is to calculate and visualise wildfire risk. The risk is a derivative of fire detection results, initial unit distribution, fire spread projection, distribution of the population in the danger zone, and GIS data. This allows indicating areas where response teams are the most needed to stop the fire before it affects people and property (houses, infrastructure, etc.). From the operational point of view, it may be achieved by implementing the following DSS-RART functionalities:

a) analysing different data sources,
b) indicating the location of hotspots,
c) calculating the risk of the hotspot development,
d) dividing wildfire area based on four risk levels (the levels reflect operational priorities to deploy response teams),
e) possibility for integration to fire spread forecast solutions,
f) feeding another DSS with information about location of hotspots, their development and specific risk,
g) indicating areas where additional firefighting resources should be placed,
h) technological openness for connecting to different sources of fire data,
i) cooperation with IT dashboard and GIS tools to visualise analysis results.

DSS-RART focuses on one of the most important decisions to be made in planning wildfire response. Much of the information that determines the results of the analysis is hidden in the algorithms and simulation models. It is not directly accessible for all the technology users. This situation has both strengths and weaknesses. On the one hand the end-user sees only what should be seen to make the resource allocation. On the other hand, access to datasets and information about the data analysed would be valuable to use DSS-RART intentionally and in the informed way.

5.2.2. Operational protocol

DSS-RARL ascribes to the universal process of wildfire response. The process is a reference to the implementation of the tool to training for firefighters. The training can be expanded with simulation mechanisms related to particular phases of the response. It is presented in Figure 45.

The use of DSS-RART addresses the majority of wildfire response phases. They are immediate disposal of wildfire responders, comprehensive reconnaissance of hazard situation (from the ground and from the air), firefighting tactics, and cooperation between firefighting entities. It supplies decision-making processes by information needed to allocate resources in the optimal amount and to optimal places. Table 23 presents examples on how to implement DSS-RART into training activities as regards particular response phases.

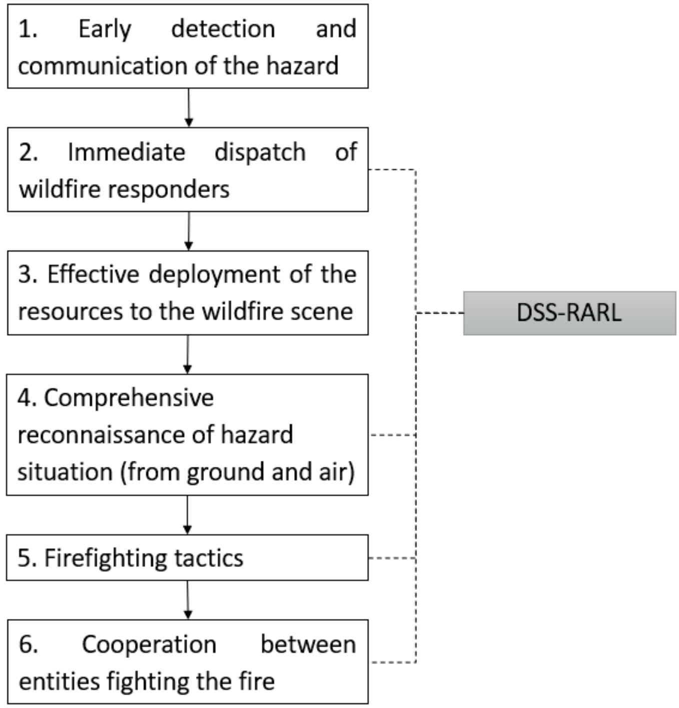

Figure 45. Role of DSS-RART in support of wildfire response training

Source: own study

Table 23. Examples of ways of implementing DSS-RART to particular phases of wildfire response

No.	Phase	Examples
1	2. Immediate disposal of wildfire responders	1) Trainee analyses the operational picture and works out needs for response teams. 2) Trainee indicates kinds of response teams needed. 3) Trainee indicates the number of response teams needed.
2	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee simulates the fire spread. 2) Trainee specifies the danger zone. 3) Trainee gathers information input to make decision on mass evacuation of people (if necessary).
3	5. Firefighting tactics	1) Trainee determines general firefighting tactics on the basis of information about the riskiest areas of the wildfire scene. 2) Trainee marks the foreseen danger zone for further planning of firefighting tactics.

Table 23 cont.

No.	Phase	Examples
4	6. Cooperation between firefighting entities	1) Trainee reviews the need to support firefighters by other entities when a fire situation becomes too serious to be handled by the fire service on its own.

Source: own study

The use of DSS-RART in wildfire response training is based on general operational activities. They are as follows:

1) Technical connection of DSS-RART to various data sources and supporting systems (for example to GIS).
2) Functional integration of DSS-RART to different data sources and supporting systems.
3) Familiarisation with the training scenario.
4) Pre-training use of DSS-RART (elements of the training scenario) to familiarise with functionalities and areas of its use when responding to a wildfire.
5) Essential use of DSS-RART to conduct training scenario (directly by a trainee or indirectly with the support of a trainer).
6) Debriefing after the training and training evaluation.

As with DSS, the practical use of DSS-RART in training for firefighters is strongly determined by functionalities of the technology. This means that a trainee is focused mostly on information to be obtained from the system, rather than on its maintenance. Once again, the significant role of technical support is highlighted. Technical support staff should be accessible for trainees to maximise the training effect and reduce operational risks stemming from technical nuances and problems.

5.2.3. Enhancement capabilities

The use of DSS-RART may enhance preparation and pre-planning activities in wildfire response. This is clearly noticeable when organising a training course for firefighters. The training can serve also to verify whether the technology meets expectations and needs of end-users. The result of such verification could serve as guidelines on how to improve it and make it more operational for firefighters.

Focusing on training-related preparation and pre-planning activities for wildfire response, the application of DSS-RART allows achieving enhancement by (i.a.):

a) immediate assigning of activities,
b) shortening the time for dispatching enough response teams to meet current operational needs,

c) prompt reporting of hotspot development possibilities in the given area and time framework,
d) improving the rationality of firefighting tactics,
e) improving situational awareness among firefighters, decision makers and other wildfire responders,
f) decreasing operational risks related to a fire by making decisions on firefighting tactics in the woods,
g) decreasing operational risks related to wrong decisions on where to initiate and conduct a firefighting action,
h) better understanding of wildfire conditions,
i) creating a background for decisions on mass evacuation of people,
j) minimising risks related to fire losses in infrastructure,
k) minimising risks related to fire losses in the natural environment.

The central category of enhancement of training-related preparation and pre-planning activities in wildfire response is to ensure that decision-makers are convinced that their decisions are optimal with respect to fire detection results, initial unit distribution, fire spread projection, distribution of the population in the danger zone, and GIS data. This points to the fact that DSS-RART is only just a tool that requires access to reliable, complete and updated data. However, the technology is an example on how the data may be effectively analysed and used to streamline firefighting action. This finds its justification in the enhancement capabilities.

In accordance with the technological point of view, application of DSS-RART to preparation and pre-planning activities in wildfire response (placing particular attention on training for firefighters) may help in seeking improvements by:

a) integration of new kinds of fire detection systems,
b) taking into account new resources distribution systems,
c) connecting new fire spread projection tools,
d) taking into account new ways of analysing the distribution of population in the danger zone,
e) connecting new GIS solutions,
f) tightening integration of communication technologies,
g) implementing new risk assessment methods,
h) introducing new algorithms for data collection for the purposes of resource allocation of response teams.

Technology improvements related to DSS-RART should focus on considering new mechanisms for risk calculation, data collection tools, data visualisation tools, and new factors that determine wildfire risk (on the basis of available information). Machine learning, deep learning and AI provide new opportunities in this context. Apart from general frameworks and approaches, the technology providers should be open to operational needs of firefighters as fire service stays on the front line of wildfire response and the DSS are designed particularly for this entity.

Enhancement capabilities are associated with technological issues and specifics of wildfire response. Consequently, some operational risks and operational threats should be described. Furthermore, they need to be taken into consideration when talking about technology development for the purposes of preparing and preplanning activities in wildfire response. The following aspects need to be considered:

1) as regards training-related preparation and pre-planning activities in wildfire response:
   a) mass scale of the incident and consequently numerous sources of information to be taken into consideration,
   b) complexity of projection algorithms and models,
   c) different data standards to be considered,
   d) difficulties in access to response teams when a number of wildfires occur at the same time,
   e) dynamic changes in factors that determine resource allocation of response teams,
   f) strong dependence on technical staff support,
   g) relatively little confidence in DSS solutions in the woods,
   h) low cognitive value without visualisation of projection results (location of the danger zone on a map);
2) as regards DSS-RART technologies:
   a) stress related to trust in new solutions,
   b) low self-maintenance skills of trainees when something goes technically wrong with a device,
   c) stress related to the use of technology (in general),
   d) cognitive overload,
   e) risk related to basing on the risk concept (referring to probabilistic character of this phenomenon) when making decisions.

Operational threats prove that the use of DSS-RART requires familiarisation with both wildfire risk assessment mechanisms and operational standards to allocate resources of response teams. The two may differ in various countries, previous experience of the fire service in wildfire response, and access to new technological solutions. This is why DSS-RART implementation in training activities needs to address national wildfire response practices. On the other hand, international emergency mechanisms may play an integrating role and facilitate deploying common standards in supporting decisions about resource allocation of response teams and response to wildfire in general (Gromek et al., 2024).

5.1.4. Safety issues for deployment of the technology

Safety challenges related to deployment of DSS-RART in training for firefighters are specific for other DSS. As a rule, trainees do not have direct access to the training field (in the woods). The access is indirect and technology plays a mediatory role between data collection processes and decision-making processes. A trainee only has access to a visualisation tool (for example a screen, a computer with GIS and DSS-RART). Consequently, the list of safety factors is limited. The following hazards should be taken into consideration (Rączkowski, 2022):

1) Hazards associated with the movement of people.
2) Electrical shock.
3) Visual radiation.
4) Biological factors.
5) Mental burden.

Table 24 reports the circumstances of hazard materialisation and specific examples.

Table 24. Examples of circumstances of hazard materialisation when using DSS-RART in firefighter training

No.	Hazard	Illustrative circumstances
1	Hazards of moving, loose, and protruding parts	a) Being hit by a screen. b) Stumbling over a computer post. c) Tripping over a cable.
2	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to the training infrastructure (a light fixture, an electrical socket).
3	Visual radiation	a) Radiation generated by screens.
4	Biological factors	a) Biological agents transmitted by other trainees (air ways). b) Biological agents accumulated on training infrastructure.
5	Mental burden	a) Situational stress. b) Strenuous competition. c) Too many sources of information (information overload). d) Inability of using the tool. e) Mental risk related to making decisions on the basis of risk and projection results.

Source: own study

On the basis of occupational safety and health standards, certain prevention measures are suggested to minimise training risks related to the specified hazards:

1) for hazards of moving, loose, sharp and protruding parts:
   a) to fix firmly the screens and cables (for example to walls),
   b) to mark safety distances (at least 1 m) around the training platform and other training areas,
   c) to ensure order in the training zone;

2) for electrical shock:
   a) to check electrical devices before every training course,
   b) to devise safety procedures to respond to any physical damages in equipment and infrastructure;
3) for visual radiation:
   a) to ensure proper illumination in training room;
4) for biological agents:
   a) to disinfect training area after every scenario,
   b) to disinfect equipment after its use,
   c) to elaborate biological safety manual,
   d) to verify the health condition of every trainee;
5) for mental burden:
   a) to minimise or eliminate competition elements from the training scenario,
   b) to ensure a friendly atmosphere during the training,
   c) to ensure that staff members support trainees in technical use of the assessment tool (including support in proper interpretation of the assessment results).

Deployment of DSS-RART into training for firefighters typically is similar to an office job. Even if a trainee is asked to work in field conditions, specific training activities are limited to handling of the system (IT dashboard or other visualisation tools). For this reason the deployment is said to be relatively safe for firefighters during training related to preparation and pre-planning activities in wildfire response.

5.3. Priority Resource Allocation based on Forest Fire Probability (DSS-PRA)

5.3.1. Technology in a nutshell

DSS that facilitate preparation and pre-planning activities differ from each other due to differences in data and calculation models. This is why not only fire detection results, initial unit distribution, fire spread projection, distribution of the population in the danger zone, and GIS data determine the allocation of resources (just like in the case of DSS-RART). There are other sets of information that may allow indicating priorities in the allocation. The illustrative tool is the Priority Resource Allocation based on Forest Fire Probability (DSS-PRA). It is a kind of DSS that calculates the likelihood of a fire in the woods. This probability is calculated using the following variables and specific data sources (SILVANUS D5.3, 2023):

a) distance to settlement [m] (data source: Landstat 8) – buffer analysis at certain distance to settlement,
b) distance to road [m] (data source: OpenStreetMap) – buffer analysis at certain distance to road,
c) elevation [m] (data source: ASTER GDEM imagery) – classification of elevation based on certain interval,
d) fuel load [tonne/km^2] (data source: Landsat 8 imagery) – fuel load estimation using vegetation indices,
e) historical fire [events per 0.75 km^2] (data source: local government) – recorded data from local disaster management authority,
f) land usage [-] (data source: Landsat 8 imagery) – supervised classification from imagery,
g) Normalized Difference Vegetation Index [-] (data source: Landsat 8 imagery) – calculation using infrared and near-infrared band,
h) population density [people per km^2) (data source: World Population Dataset) – classification of population density based on certain interval,
i) Gross Domestic Product [21 million idr per km^2] (data source: World Bank Database) – Classification of Gross Domestic Product based on certain interval,
j) vegetation type [-] (data source: Landstat 8 imaginery) – supervised classification from imagery,
k) aspect [°] (data source: ASTER GDEM imaginery) – aspect calculation from elevation data,
l) slope [°] (data source: ASTER GDEM imaginery) – slope calculation from elevation data,
m) temperature [°C] (data source: ERA5 Reanalysis) – average of annual temperature,
n) precipitation [mm per y] (he data source: ERA5 Reanalysis) – total annual rainfall.

Figure 46 presents high-level process of data fusion in DSS-PRA.

DSS-PRA may be useful for personnel involved in decision-making processes in wildfire response. This perspective is also valid for potential participants of a training course for firefighters. In accordance with the level of decisions to be made and practical access to data, they could be command centres, emergency management centres, disaster management centres, and crisis management centres. It should be emphasized that the tool may be deployed even before a fire season to make *ex ante* analysis and to prepare operational plans for the future. Many data sources integrated to DSS-PRA enable drawing trend lines in the data collected. This may broaden the potential group of beneficiaries to researchers and experts who may be involved in wildfire response as they address their daily work to fire protection of the woods.

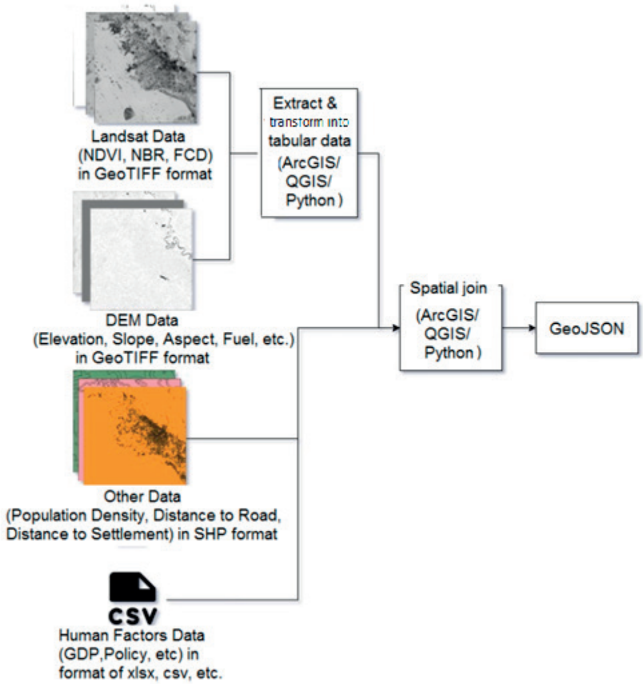

Figure 46. Community Engagement Model for Emergency Management
Source: (ADRHC, 2013)

DSS-PRA provides the priority level of resource allocation for wildfire response. In addition, it estimates levels of fire probabilities. These are its main functionalities. In detail, the technology allows the following (SILVANUS, 2024):

a) provide levels of fire probabilities regarding their characteristics,
b) provide the priority level of resource allocation according to their characteristics and area level,
c) provide 14 variable characteristics of the woods (both human-related characteristics and physical-environmental characteristics).

These three directions determine the basic DSS-RART functionalities, which have been presented below:

a) analysing different data sources,
b) analysing the danger zone as an entirety,
c) possibility of comparing different zones in the woods and to prioritize them due to probability of fire occurrence,
d) possibility to focus on particular variables that determine wildfire probability,
e) dividing wildfire area based on different levels specified for particular variables used,
f) possibility of integration to fire spread forecast solutions,

g) feeding information to another DSS by as to probability of a fire in the wooded area,
h) indicating areas where additional firefighting resources should be provided,
i) cooperation with IT dashboard and GIS tools to visualise analysis results.

The view of the results of using DSS-PRA for the purposes of wildfire response is presented in Figure 47. The figure illustrates not only decision support result for the given area but also data layers considered in the computing process, and legend of priority resource allocation scores.

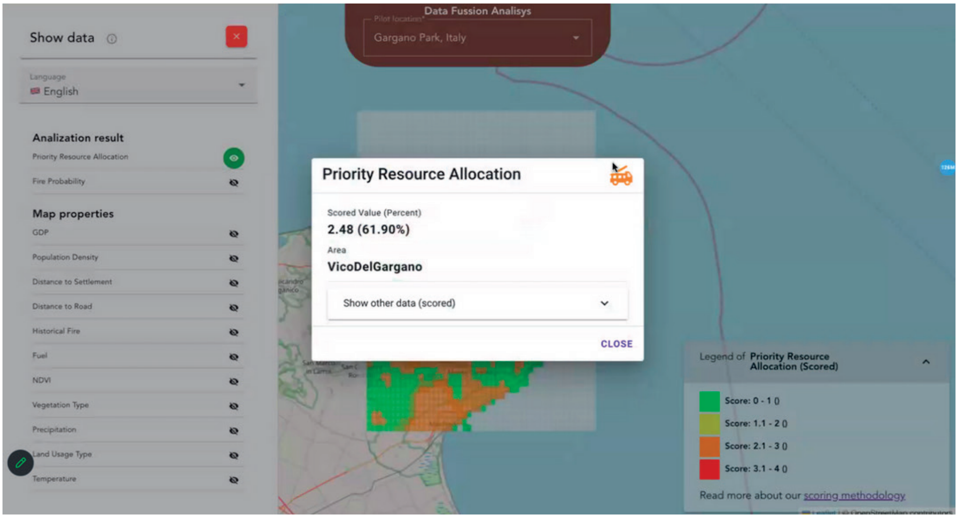

Figure 47. View of analysis results obtained in DSS-PRA
Source: (SILVANUS, 2024)

DSS-PRA focuses on the probability of a fire. It is not enough to deal with wildfire risk but a significant issue is to execute a specific assessment. The focus on probability is reasonable especially in the light of priority resource allocation. It contributes to wildfire risk reduction by preparing firefighting resources to be deployed in places where hotspots are highly probable and expected to materialise. The tool may also be applied in the fire season when every hotspot may be a disaster trigger.

5.3.2. Operational protocol

DSS-PRA can be implemented into the training for firefighters. The universal process of wildfire response is an appropriate implementation structure as firefighters should know how the technology can be used in the 'step-by-step' formula. The training can be expanded with priority resource allocation modelling related to particular phases of the response. This has been presented in Figure 48.

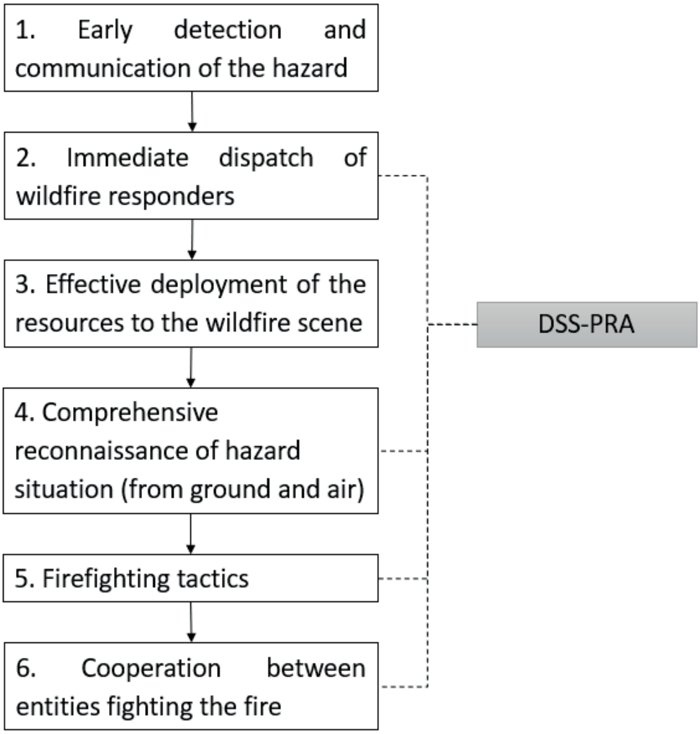

Figure 48. Role of DSS-PRA in support of wildfire response training
Source: own study

The use of DSS-PRA corresponds to the training and refers to many response phases. They are immediate disposal of wildfire responders, comprehensive reconnaissance of hazard situation (from the ground and from the air), firefighting tactics, and cooperation between firefighting entities. It provides information to decision-making processes needed to allocate resources in an optimal way. Examples on how to implement DSS-PRA into training activities as regards particular response phases are presented in Table 25.

The use of DSS-PRA in wildfire response training is based on the following general operational activities:

1) Technical connection of DSS-PRA to different data sources.
2) Functional integration of DSS-PRA to different data sources and supporting systems.
3) Familiarisation with the training scenario.
4) Pre-training use of DSS-PRA (elements of the training scenario) to become familiarised with functionalities and areas of its use when responding to a wildfire.

Table 25. Examples ways of implementing DSS-PRA to particular phases of wildfire response

No.	Phase	Examples
1	2. Immediate dispatch of wildfire responders	1) Trainee analyses the operational picture and determines needs for response teams. 2) Trainee indicates areas of placement of ad hoc response teams. 3) Trainee indicates administrative territories to increase operational readiness level for response teams.
2	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air) reconnaissance	1) Trainee simulates different fire conditions with the use of different sets of values for particular variables. 2) Trainee specifies the danger zone. 3) Trainee collects information input to make decisions on mass evacuation of people (if necessary).
3	5. Firefighting tactics	1) Trainee determines general firefighting tactics on the basis of information about the most probable territories of fire occurrence. 2) Trainee designates the foreseen danger territories for further planning of firefighting tactics.
4	6. Cooperation between firefighting entities	1) Trainee verifies the need to support firefighters by other entities when the situation of the wildfire is too serious to be handled by local fire service on its own.

Source: own study

5) Essential use of DSS-PRA to carry out training scenario (directly by a trainee or indirectly with the support of a trainer).
6) Debriefing after the training and training evaluation.

Deployment of DSS-PRA comes down to making a data input to the system and reading the result. The illustrative result is presented in Figure 49.

The result interpretation and formulating relevant decisions make up the overall decision-making process but go beyond the use of DSS-PRA. This is the reason why the technology should be incorporated into overall training procedure.

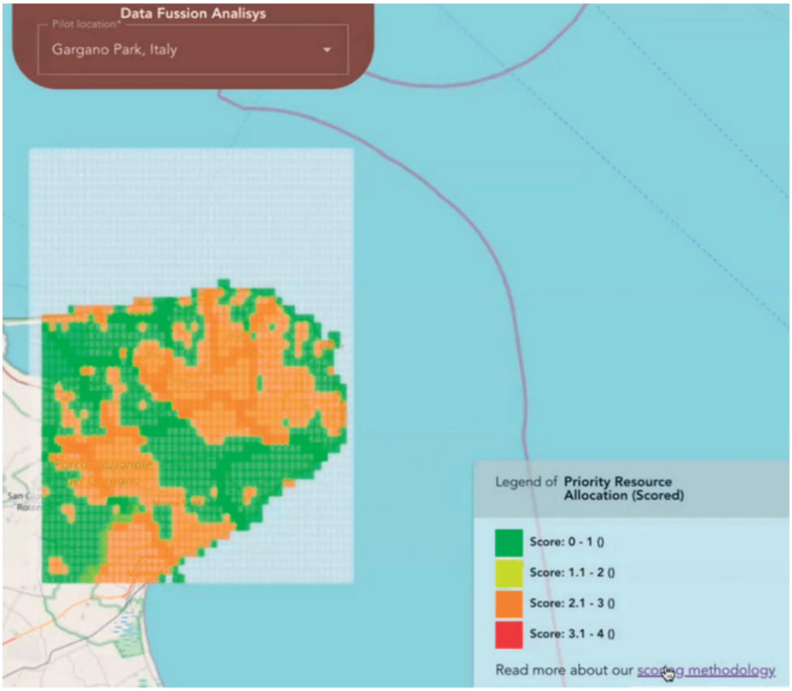

Figure 49. View of probability calculation results obtained in DSS-PRA
Source: (SILVANUS, 2024)

5.3.3. Enhancement capabilities

The concept of DSS-PRA proves that DSS is a flexible technological platform to support wildfire response by integrating and analysing many kinds of information from different data sources. Improvement of DSS-PRA may facilitate enhancing the preparation and pre-planning activities in wildfire response. Technology development can be a trigger for enhancement of DSS-PRA with a positive impact on these activities.

In line with training-related preparatory activities and initial fire response planning and the application of DSS-PRA, the following types of enhancement may be achieved by (i.a.):

a) immediate assignment of activities,
b) shortening the time for dispatching response teams,
c) prompt reporting of hotspot development possibilities in the given area and time framework,
d) improving the rationality of the firefighting strategy,
e) improving the situational awareness among firefighters, decision makers and other wildfire responders,

f) better understanding of wildfire conditions,
g) creating a background for decisions on mass evacuation of people.

The enhancement capabilities for training-related preparation and pre-planning activities are of a strategic character, because of the specifics of DSS-PRA output. The output concerns the probability score and the percentage value for a relatively extensive area (for example for a national park). The level of detail is too low to leverage firefighting tactics but is sufficient to support firefighting strategy, emergency management, disaster management and crisis management. From this viewpoint, DSS-PRA may serve as framework for the operationalization of the general situational picture with the use of other DSS and technological tools.

Given the technological issues, the application of DSS-PRA in preparation and pre-planning activities for wildfire response (with particular attention on training for firefighters) may help in seeking improvements by:

a) deploying new kinds of variables,
b) considering new resource distribution systems,
c) implementing new fire probability equation,
d) developing a development probability assessment method into new risk assessment method,
e) connecting new GIS solutions,
f) adopting new algorithms for data collection for the purposes of resource allocation based on fire likelihood.

Technology improvers of DSS-PRA should be open to other probability variables and other sources of data and information. IoT, smart solutions (smart cities, smart safety, smart security, etc.) and the technosphere of national security systems (including firefighting and rescue systems, emergency systems, disaster management systems, etc.) may provide inspirations for DSS development in the analysed context.

Technological issues and specifics of wildfire response leverage enhancement capabilities. It is noticeable not only in potential improvements but also in case of some operational risks and operational threats. They need to be considered when talking about technology development for the purposes on preparation and preplanning activities in wildfire response. The following aspects need to be taken into account:

1) as regards training-related preparation and pre-planning activities for wildfire response:
    a) many data sources to be connected,
    b) complexity of analysis algorithms and models,
    c) different data standards to be considered,
    d) difficulties in access to response teams when a number of wildfires occur at the same time,
    e) strong dependence on technical staff support,

    f) relatively little confidence in DSS solutions in the woods,
    g) low cognitive value without visualisation of projection results (location of the danger zone on a map),
    h) probability that cannot be equated with risk (probability is one of risk variables only and risk is more than solely a probability),
    i) strategic perspective of analysis and, consequently, low application in tactical and field levels of wildfire response;
2) as regards DSS-PRA technologies:
    a) stress associated with having to rely on new solutions,
    b) low self-maintenance skills of trainees when something goes technically wrong,
    c) stress related to the use of technology (in general),
    d) cognitive overload,
    e) operational risk related to basing on probability only when making decisions.

DSS-PRA is unable to solve all operational problems related to allocation of firefighting resources. However, it provides a situational background to serve as a framework for organisational solutions in the decision-making process. Results of its use enable ascribing priorities to particular areas (territories) and then dispatching resources of wildfire responders. Even during a training course, the operational hazards and operational threats identified need to be taken into consideration to improve the usefulness of technology for firefighters.

5.3.4. Safety issues for deployment of the technology

Training for firefighters should be organised in a way that ensures personal safety of the attendees. This is why DSS-PRA should be analysed also from the viewpoint of occupational safety and health concerns. Fortunately, the technology plays a mediatory role between data collection processes and decision-making processes and trainees do not need direct access to the training field (for example in the woods). Access to a visualisation tool is sufficient to learn and use DSS-PRA functionalities. To achieve the training objectives, the training post should comprise a screen and a computer with DSS-PRA. Consequently, the following hazards should be considered (Rączkowski, 2022):

1) Hazards associated with the movement of people.
2) Electrical shock.
3) Visual radiation.
4) Biological factors.
5) Mental burden.

Table 26 reports the circumstances of hazards materialisation and specific examples.

Table 26. Illustrative circumstances of hazard materialisation when using DSS-PRA to train firefighters

No.	Hazard	Illustrative circumstances
1	Hazards of moving and loose, and protruding parts	a) Being hit by a screen. b) Stumbling over a computer post. c) Tripping over a cable.
2	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to the training infrastructure (a light fixture, an electrical socket).
3	Visual radiation	a) Radiation generated by screens.
4	Biological factors	a) Biological agents transmitted by other trainees (air ways). b) Biological agents accumulated on training infrastructure.
5	Mental burden	a) Situational stress. b) Stressful competition. c) Too many sources of information (information overload). d) Inability of using the tool. e) Mental risk related to making decisions on the basis of risk and projection results.

Source: own study

As it comes to occupational safety and health standards, reference prevention measures are suggested to minimise training risks related to the following specified hazards:

1) for hazards of moving, loose, sharp and protruding parts:
   a) to fix firmly the screens and cables (for example to walls),
   b) to mark safety distances (at least 1 m) around the training platform and other training areas,
   c) to ensure order in the training zone;
2) for electrical shock:
   a) to check electrical devices before every training,
   b) to devise safety procedures to respond to any physical damage in equipment and infrastructure;
3) for visual radiation:
   a) to ensure proper illumination in the training room;
4) for biological agents:
   a) to disinfect the training area after every scenario,
   b) to disinfect equipment after its use,
   c) to devise a biological safety manual,
   d) to verify the health condition of every trainee;

5) for mental burden:
   a) to minimise or eliminate competition elements from the training scenario,
   b) to ensure a friendly atmosphere during a training course,
   c) to ensure staff members to support trainees in the technical use of the assessment tool (including support in proper interpretation of the analysis results).

Deployment of DSS-PRA into training for firefighters typically resembles an office job. The trainee does not have to be directly present in the field conditions to learn the tool functionalities. The firefighter must be able to handle the system only. Access should be provided to IT dashboard or another visualisation tool is required. The deployment of DSS-PRA for training purposes is said to be relatively safe for firefighters when learning issues related to preparation and pre-planning activities in wildfire response.

5.4. Evacuation Route Planning (DSS-ERP)

5.4.1. Technology in a nutshell

Evacuation is one of the basic methods of protecting people, property and animals when a wildfire occurs (Mihalus et al., 2024; Szajewska, 2024). It is also an emergency procedure if the hazard develops and firefighting entities are directly endangered as to their life and health. In such circumstances evacuation analyses should be community-oriented because every wildfire area is characterised by a unique set of roads, wildfire risk factors, distribution of shelters, and assets to evacuate (Kim et al., 2024). Furthermore, every community has its own profile of vulnerability to evacuation (Sun et al., 2024; Szajewska, 2024). These issues should be addressed with respect to wildfire response and considered in training for firefighters.

An example on ways of deploying evacuation issues in overall proceeding in wildfire response is the Evacuation Route Planning (DSS-ERP). It is a kind of DSS technologically integrated to multiple data sources and calculation tools. Its general idea is presented as Evacuation Route Planning Module Triggering in Figure 50.

The central functional point of DSS-ERP is the command centre (main command centre and/or forward command centre). Even if this technology is dedicated primarily to firefighters, specific functionalities may be applied to emergency management centres, disaster management centres and crisis management centres. The catalogue of potential technology beneficiaries is open also for researchers and forest planners for analysing, shaping and managing evacuation conditions in the woods before a fire occurs. The centre or another DSS-ERP operational point obtains

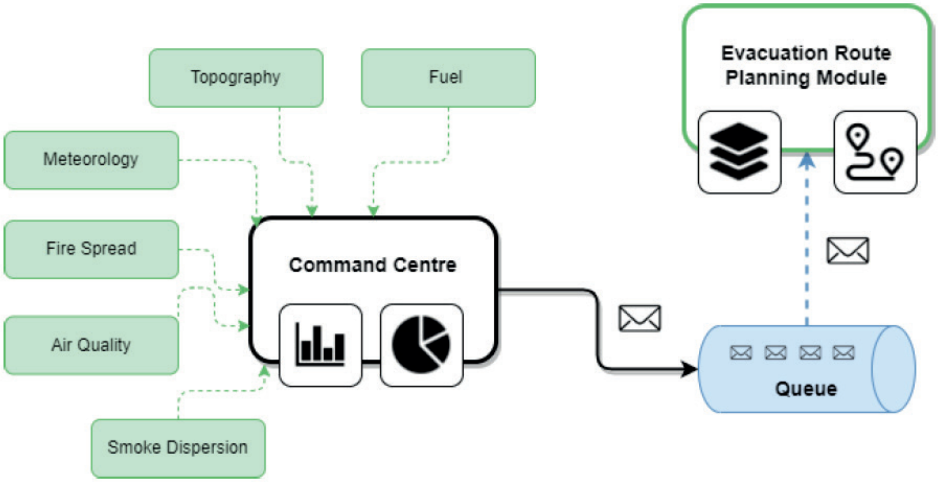

Figure 50. Evacuation Route Planning Module Triggering
Source: (SILVANUS D5.3, 2023)

information concerning fuel, topography, meteorology, fire spread, air quality and smoke dispersion. Particular attention is placed on identifying places where thermal radiation and air quality does not allow remaining in place and evacuation becomes necessary, and to indicate routes to emergency shelters.

Implementation of DSS-ERP relies on making the following steps that may be identified as its main functionalities (SILVANUS D5.3, 2023):

a) assessing the risk (evaluating potential hazards and threats),
b) analysing the population (assessing the demographic characteristics of the affected population),
c) defining safe areas (identifying safe locations for evacuees),
d) selecting routes (establishing the most suitable evacuation routes),
e) simulation testing (carrying out simulations of evacuation for the evaluation purposes).

Results obtained from the execution of this procedure is illustrated in Figure 51.

The main technological functionalities may be transferred into specific operational functionalities associated with expectations and needs of firefighters. Considering these expectations and needs is crucial to tailor the technology to real conditions of wildfire response and to make the tool useful for end-users. Therefore, the following specific functionalities should be highlighted:

a) analysing fire manifestations that pose direct danger to human life and health of people and require action from firefighters to protect them,
b) visualising fire manifestations on a map (especially the range of smoke cloud in given time intervals),

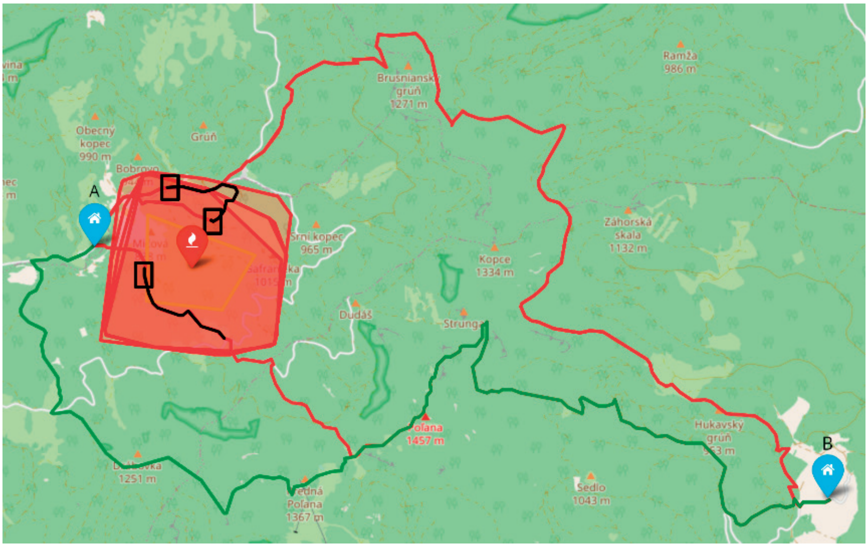

Figure 51. Results of the use of DSS-ERP
Source: (SILVANUS, 2024)

c) simulating the development of a hazard situation in given time intervals,
d) providing information to population in danger (demographic characteristics and structure),
e) calculating safety distances from the danger zone,
f) indicating primary shelters for evacuees with respect to wildfire manifestations,
g) indicating secondary shelters for evacuees with respect to the fire spread forecast,
h) marking evacuation routes with respect to wildfire manifestations and the fire spread forecast,
i) marking starting and end points of evacuation routes to facilitate the organisation of the evacuation process,
j) simulation of evacuation process to verify initial organisational assumptions and create space for their evaluation,
k) shaping situational awareness by taking into account the evacuation of people concurrently with a firefighting action.

From the functional point of view, the use of DSS-ERP comes down to analysing evacuation circumstances and conditions, and setting out safe evacuation routes to shelters far enough to secure people against negatively perceived wildfire manifestations (thermal radiation and toxic smoke). For this reason the tool deploys the smoke dispersion model and is integrated with the fire spread model. It is also connected to the path tracking functionality which bases on GIS solutions.

5.4.2. Operational protocol

As mass evacuation of people may be organised simultaneously with the necessary firefighting action, DSS-ERP is an advantageous tool to consider these issues in wildfire response. It can be applied in training for firefighters appropriately to preparation and pre-planning activities for the response. The first main reason is to ensure that wildfire responders are able to moderate the evacuation process and support people in danger to move to emergency shelters. The second main reason is to make sure that evacuation does not impede the firefighting action, and the firefighting action does not restrain the evacuation process. The firefighter training may be expanded with evacuation route planning related to particular phases of the response. This has been presented in Figure 52.

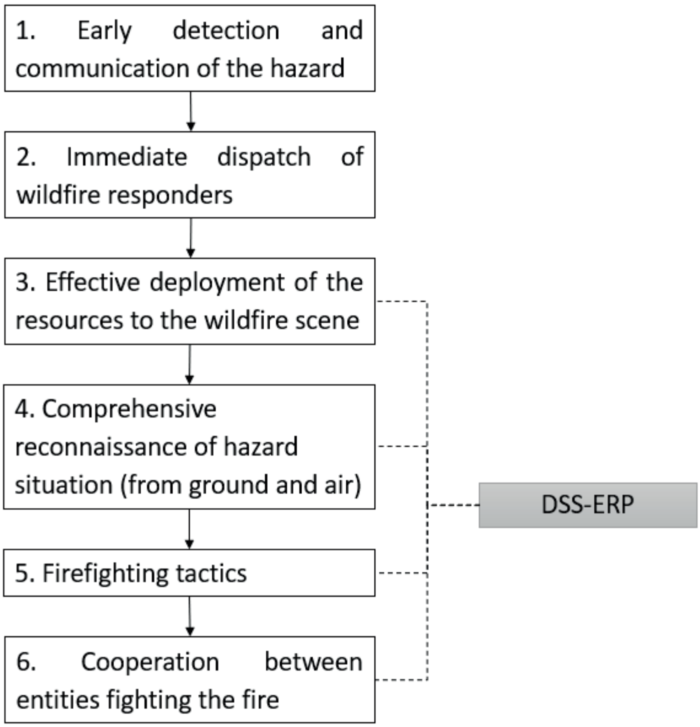

Figure 52. Role of DSS-ERP in support of wildfire response training

Source: own study

The use of DSS-ERP may correspond to training of firefighters as regards four last phases of wildfire response, i.e. effective deployment of resources to the wildfire scene, comprehensive reconnaissance of the hazard situation, firefighting tactics, and cooperation between firefighting entities. It supports decision-making processes by providing information necessary for the optimal use of roads on the wildfire scene and in its vicinity as such roads can be used by firefighters approaching to the scene and also by evacuees moving in the opposite direction. Examples on how to implement DSS-ERP in training activities with respect to particular response phases are presented in Table 27.

Table 27. Examples of ways of deploying DSS-ERP in particular phases of wildfire response

No.	Phase	Examples
1	3. Effective deployment of the resources to the wildfire scene	1) Trainee analyses routes used for voluntary (self) evacuation to exclude them from the arrival of firefighters when necessary (reduction of counterflows). 2) Trainee suggests evacuation routes that are not in opposition to the arrival of firefighters to the wildfire scene (reduction of counterflows).
2	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee identifies potential places where a counterflow may occur. 2) Trainee analyses potential the load on roads for further water supply planning. 3) Trainee indicates shelters which might be used during wildfire response when civilians are in danger due to wildfire manifestations. 4) Trainee indicates shelters to be used during wildfire response when firefighters are in danger.
3	5. Firefighting tactics	1) Trainee adjusts the firefighting tactics to the mass evacuation of people. 2) Trainee adjusts the water supply process to the mass evacuation of people. 3) Trainee plans to conduct the firefighting action with limited human firefighting resources after their use for the purposes of mass evacuation of people.
4	6. Cooperation between firefighting entities	1) Trainee reviews the need to support firefighters by other entities when evacuees need support from public services and the fire service is unable to ensure such support on its own. 2) Trainee indicates places where supporting entities should be located to manage the evacuation process. 3) Trainee indicates where support units should be located to direct firefighters to the scene of a fire without impeding the evacuation process.

Source: own study

The use of DSS-ERP in wildfire response training is based on the following general operational activities:

1) Technical connection of DSS-ERP to different data sources.
2) Functional integration of DSS-ERP to different data sources and supporting systems.
3) Familiarisation with the training scenario.
4) Pre-training use of DSS-ERP (elements of training scenario) to familiarise with functionalities and areas of its use when responding to a wildfire.
5) Essential use of DSS-ERP to conduct the training scenario (directly by a trainee or indirectly with the support of a trainer).
6) Debriefing after the training and training evaluation.

As it comes to the practical point of view, DSS-ERP is a supporting tool to plan wildfire response that focuses not only on the firefighting action but on the wider perspective of the response. Firefighters do not operate in a societal vacuum. It means that there could be people in the danger zone (tourists, inhabitants, etc.), and their safety has a higher priority that the natural environment. The environment is important but not so important as human life and health. DSS-ERP may facilitate making optimal decisions to ensure societal security with minimal losses in the environment.

5.4.3. Enhancement capabilities

Application of DSS-ERP highlights that enhancement of wildfire response should consider not only the firefighting action but also other activities performed to handle a wildfire. Mass evacuation of people is the significant one to ensure societal security in the context under consideration. The evacuation specifics may also determine technology improvements when firefighters want to use solutions helpful to managing the hazard in a holistic way.

As far as the training-related preparation and pre-planning activities for wildfire response are concerned, DSS-ERP may influence their improvements by (i.a.):

a) optimising the use of roads at the wildfire scene and in the vicinity,
b) optimising the arrival time of fire engines,
c) optimising the evacuation time for people,
d) providing information about shelters that may be used by firefighters in case of emergency (for example when fire development poses a direct danger to firefighters' life),
e) reducing operational risks related to simultaneous conduct of a firefighting action and mass evacuation of people,
f) rationalising the distribution of resources to cover possibly all significant aspects of wildfire response (at least the firefighting action and the mass evacuation of people),

g) improving the rationality of the firefighting strategy,
h) improving situational awareness among firefighters, decision makers and other wildfire responders,
i) better understanding of wildfire conditions.

The enhancement capabilities prove that wildfire response is much more than merely a firefighting action. Firefighters should be aware of this fact and also that training is a good opportunity to shape a broad understanding of the response. This is why enhancement capabilities concern firefighting action indirectly and shed a light on activities that are also important in the context under consideration. The use of DSS-ERP opens possibilities of broad cooperation between firefighters and other entities interested in evacuation-related information (public administration, local authorities, police troops, armed forces, medical rescue teams, voluntary organisations, etc.). Such cooperation can be reflected in training curricula.

Focusing on the technological point of view, the application of DSS-ERP to preparation and pre-planning activities for wildfire response (placing particular attention on training for firefighters) may cause the following improvements:

a) identification of new contexts of wildfire response to be considered,
b) deploying new evacuation models,
c) applying new fire spread models in calculations,
d) integration of new evacuation simulators,
e) considering analyses of derivative threats to mass evacuation of people (for example in case of traffic accidents),
f) considering analyses of derivative threats of a wildfire (for example factors affecting critical infrastructure in the woods),
g) deploying optimisation algorithms for distribution of evacuees to shelters in the safety zone.

Improvement possibilities of DSS-ERP stem from the software character of the tool. It means that the system is technically a flexible platform and allows implementing more functionalities and/or evaluating the existing ones. They could include modelling and simulation solutions as well as new contexts of their use (for example infrastructure protection against wildfire manifestations). The important enhancement direction is to optimise overall efforts that define wildfire response. This reflects the specifics of decision-making processes and may be applied in case of DSS-ERP.

Despite a number of advantages in the use of DSS-ERP for preparation and pre-planning activities in wildfire response, it is necessary to mention some operational risks related to practical implementation of this tool. Facing these risks may facilitate the implementation process. The following issues must be taken into consideration:

1) as regards training-related preparation and pre-planning activities for wildfire response:
   a) numerous data sources to be connected,

   b) complexity of analysis algorithms and models,
   c) different data standards to be considered,
   d) difficulties in access to response teams when many wildfires occur at the same time,
   e) strong dependence on technical staff support,
   f) relatively low confidence in DSS solutions in the woods,
   g) low cognitive value without the visualisation of projection results (the location of shelters and evacuation routes on a map),
   h) relatively low confidence in the results of mass evacuation simulations,
   i) relatively low confidence in the results of smoke spread simulations (especially considering a developed wildfire which is able to shape environmental conditions);
2) as regards DSS-PRA technologies:
   a) stress related to trusting new solutions,
   b) low self-maintenance skills of trainees by trainees when something goes technically wrong,
   c) stress related to the use of technology (in general),
   d) cognitive overload,
   e) operational risk related to basing on results of computational models,
   f) operational risk related to basing on results of simulations.

Technical support for trainees and permanent implementation of new computational solutions face operational risks. It should be also highlighted that projection and simulation results determine only some reflections of reality and entail uncertainty. Trainees, training organisers and trainers must be aware of this fact. This is especially important for mass evacuation of people. There are no ideal evacuation simulators (Kielch, Gromek, 2020), and their integration to hazard development models does not perfectly reflect output of the real data experiments.

5.4.4. Safety issues for deployment of the technology

The use of DSS-ERP during training for firefighters does not generate serious hazards or threats for the participants. This stems from its specifics and from the limited impact of harmful factors. A firefighter does not need to participate in the evacuation to analyse and plan it. Access to a computational post with a visualisation tool is sufficient to achieve relevant training goals. From the viewpoint of occupational safety and health, the following hazards should be considered (Rączkowski, 2022):

1) Hazards associated with the movement of people.
2) Electrical shock.
3) Visual radiation.
4) Biological factors.
5) Mental burden.

Table 28 lists the circumstances of hazard materialisation along with specific examples.

Table 28. Illustrative circumstances of hazard materialisation when using DSS-ERP to train firefighters

No.	Hazard	Illustrative circumstances
1	Hazards of moving and loose, and protruding parts	a) Being hit by a screen. b) Stumbling on a computer post. c) Tripping over a cable.
2	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to the training infrastructure (a light fixture, an electrical socket).
3	Visual radiation	a) Radiation generated by screens.
4	Biological factors	a) Biological agents transmitted by other trainees (air ways). b) Biological agents transmitted by other trainees. c) Biological agents accumulated on training infrastructure.
5	Mental burden	a) Situational stress. b) Stressful competition. c) Too many sources of information (information overload). d) Inability of using the tool. e) Mental risk related to making decisions on the basis of simulation results.

Source: own study

In accordance with occupational safety and health standards, reference prevention measures are suggested to reduce training risks related to the specified hazards:

1) for hazards of moving, loose, sharp and protruding parts:
   a) to fix firmly the screens and cables (for example to walls),
   b) to mark safety distances (at least 1 m) around the training platform and other training areas,
   c) to ensure order in the training zone;
2) for electrical shock:
   a) to check electrical devices before every training,
   b) to devise safety procedures to respond to any physical damages in equipment and infrastructure;
3) for visual radiation:
   a) to ensure proper illumination in the training room;
4) for biological agents:
   a) to disinfect the training area after every scenario,

   b) to disinfect equipment after its use,
   c) to devise a biological safety manual,
   d) to verify the health condition of every trainee;
5) for mental burden:
   a) to minimise or eliminate competition elements from the training scenario,
   b) to ensure a friendly atmosphere during a training course,
   c) to ensure that staff members support trainees in technical use of the assessment tool (including support in proper interpretation of the analysis results).

The deployment of DSS-ERP for training purposes is relatively safe for firefighters during a training course related to preparation and pre-planning activities in wildfire response. On the one hand it is hard to imagine mass evacuation of people without being on evacuation routes. On the other hand, evacuation is not a safe procedure. It should be initiated only when the risks of staying at a place are greater than the risks of moving to a shelter. When a wildfire occurs, the goal of firefighters is first of all to plan the firefighting operation. Consequently, DSS-ERP is applicable in training for firefighters to make a broader operational perspective and to facilitate adjusting firefighting plans to the conditions of mass evacuation of people. Staying at the training post in office conditions is sufficient to do so.

Chapter 6

Enhancement of preparation and pre-planning activities for wildfire response with the use of reference societal involvement tools for firefighter training

6.1. Augmented reality / virtual reality training for firefighters

6.1.1. Technology in a nutshell

Augmented reality (AR) and virtual reality (VR) are commonly used technologies for the purposes of safety trainings (Man et al., 2024; Scorgie et al., 2024). They are also applied in wildfire preparedness and response (Molan, Weber, 2021; SILVANUS, 2024).

As far as wildfire management is concerned, main beneficiaries of AR and VR technologies are firefighters, forest services, and other entities directly involved in operational activities (for instance emergency commanders). Their practical training entails a relatively high personal risk for trainees and requires significant organisational efforts and resources (for example the training field, firefighting vehicles, extinguishing equipment, simulation means etc.). Full scale fires are impossible to simulate in real conditions formula due to direct danger to human/animal life and environment. It may also be forbidden because of legal restrictions. The use of AR and VR technologies allows handling these challenges, and also makes the training cheaper and easier to organise.

The core AR/VR functionality is to reflect an element of reality to present a background for training purposes. The background is reflected by a scenario that uniquely connects wildfire conditions and firefighting procedures to be conducted. The AR/VR technology gives an opportunity of checking the effectiveness of wildfire response, simulating time stress and visualising effects of firefighting action. In accordance to its specifics, the technology may be used by firefighters as well as by their trainers (the trainers can moderate a scenario and/or support trainees or may be trained as well in the formula of "train the trainers").

In detail, AR/VR technology allows for virtual presentation of:

1) a wildfire scene (i.a.):
    a) general land relief,
    b) natural obstacles,
    c) reservoirs and watercourses,
    d) afforestation (tree species and relevant density),
    e) time of day,
    f) forest roads,
    g) places of resources concentration;
2) weather conditions (i.a.):
    a) wind direction,
    b) wind force,
    c) precipitation,
    d) insolation;
3) wildfire phenomenon (i.a.):
    a) flame intensity,
    b) flame height,
    c) extent of the flame zone,
    d) extent of the smoke zone,
    e) smoke intensity,
    f) burned materials;
4) equipment (i.a.):
    a) firefighting vehicles,
    b) vehicles of other entities that conduct wildfire response (including quads, helicopters, and planes),
    c) firefighting lines and specific equipment necessary to put out a fire,
    d) personal protective means;
5) other elements that determine wildfire management, including the cascading effect of hazard development (i.a.):
    a) high voltage lines,
    b) gas pipes,
    c) vulnerable stands,
    d) HazMat storages,
    e) Illegal dumps.

Moreover, the technology is also appropriate to simulate and/or verify (i.a.):

1) the effectiveness of a particular responder (for example a firefighter),
2) the correctness of a particular response procedure,
3) the coordination of an entire firefighting operation,
4) communication flows during wildfire response.

Deployment of AR/VR technologies requires access to dedicated hardware and software. As regards the hardware, there is a lot of equipment items that may be used for the training needs. They can be divided as follows:

1) computational unit(s),
2) visualisation tools (for example goggles, screens),
3) manipulation tools (joysticks, platforms, firefighting nozzles, etc.),
4) additional items (i.a. speakers, smoke projectors).

As far as software goes, it is comprised in computational mechanisms and a virtual world (artificial reality).

Figure 53 presents an illustrative view of a virtual world projected by VR tool for the purposes of firefighter training.

Figure 53. Illustrative view of a virtual world projected by a VR tool for firefighter training
Source: (SILVANUS, 2024)

As regards the SILVANUS project, an optimal training effect strengthened by AR/VR potential may be achieved when specific technologies are used during the first phase of wildfire management. This means preparation and pre-planning activities for wildfire response, especially with the use of VR technology for online/offline training for first responders and to apply the AR/VR solution to support live communication between first responders. The technological application should be designed for training in both online formula and offline formula. The minimum functionalities are 1 role, 1 environment and 1 scenario. The environment needs to present a real case study (wildland area). The scenario should reflect real operational protocols in wildfire response.

6.1.2. Operational protocol

Operational protocol related to the use of AR/VR in wildfire training should correspond to a universal process of wildfire response. Figure 54 shows the process and indicates process elements that may be supported by AR/VR-determined training.

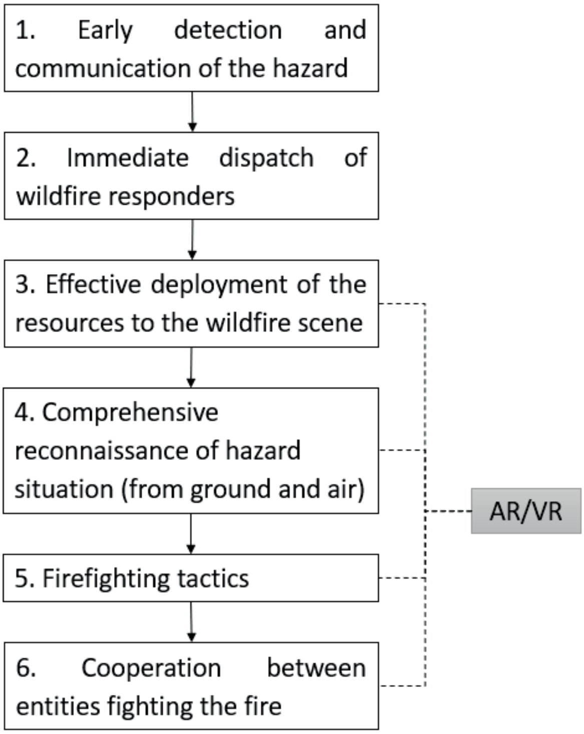

Figure 54. Use of AR/VR technologies in support of wildfire response training
Source: own study

The most noticeable technology impact involves effective deployment of resources to the wildfire scene, comprehensive reconnaissance of hazard situation (from the ground and from the air), firefighting tactics and cooperation between firefighting entities. It does not mean that there is no impact on the rest of wildfire response phases but rather emphasizes that AR/VR specifics matches the essential multi-entity response activities. Table 29 compiles examples on how to use AR/VR technologies in particular phases indicated on Figure 54.

Table 29. Examples of ways of making use of AR/VR technologies in particular phases of wildfire response

No.	Phase	Examples
1	3. Effective deployment of the resources to the wildfire scene	1) Trainee simulates arrival to the wildfire scene using different methods, in varying weather conditions. 2) Trainee simulates arrival to the wildfire scene seeking for the best route in difficult terrain conditions. 3) Trainee indicates the proper arrival way to other firefighting entities. 4) Trainee seeks alternative direction and arrival route when a wildfire develops.
2	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee analyses the wildfire scene from the general air perspective to collect basic reconnaissance information. 2) Trainee rides a quad and is obligated to collect reconnaissance information from many different places on the wildfire scene. 3) Trainee simulates flying a UAV, needs to optimise the flight route, and collects reconnaissance information. 4) Trainee simulates operating UGV, needs to optimise robot route, and collects reconnaissance information.
3	5. Firefighting tactics	1) Trainee prepares first orders to organise the wildfire response on the basis of information collected with the use of VRs. 2) Trainee simulates extinguishing of a fire with the use of basic firefighting water equipment (a nozzle, a hosing line, etc.). 3) Trainee simulates extinguishing of a fire with the use of basic firefighting hand equipment (a suppressor, a shovel, etc.). 4) Trainee simulates deliberate arson to create a demineralised strip of land to contain a developing fire.
4	6. Cooperation between firefighting entities	1) Trainee directs other fire engines to the wildfire scene using the optimal arrival route when a hazard develops. 2) Trainee navigates a helicopter or a plane to make water drop for fire suppression from the air. 3) Trainee communicates with other trainees to exchange operational information. 4) Trainee simulates decision evaluation by giving orders in case of a cascading effect of the development of a hazard.

Source: own study

The use of AR/VR technologies in wildfire response training is based on the following general operational activities:

1) Familiarisation with the training scenario.
2) Instruction for proper use of AR/VR manipulators and/or stands.
3) Pre-training use of AR/VR manipulators and/or stands in the semi-scenario (elements of training scenario).
4) Essential use of AR/VR manipulators and/or stands to conduct training scenario.
5) Debriefing after the training and training evaluation.

The operational protocol for the use of AR/VR solutions in training of wildfire response may be concretised in multiple ways on the basis of training scenario and accessible equipment. Furthermore, the protocol should be tailored to cognitive and manual abilities of trainees. Not everyone is able to effectively apply manipulators and the need to familiarise with the technology may leverage the training effectiveness.

6.1.3. Enhancement capabilities

Cognitive training-related connection of AR/VR solutions with wildfire response specifics provides unique possibilities for identifying the enhancement potential for both preparation and pre-planning activities for wildfire response and the technologies.

The use of AR/VR solutions gives significant additional value to the training. Namely, it allows visualising quasi-real wildfire conditions without affecting firefighting in specific hazards (smoke, flames, etc.). Figure 55 presents the view of a wildfire scene designed in VR software.

Figure 55. View of wildfire scene designed in VR software
Source: (Wu et al., 2023)

As far as preparation and pre-planning activities for wildfire response are concerned, the application of AR/VR technologies allows significant enhancement by:

a) quick visualisation of the wildfire scene,
b) reiterating multiple training scenarios by the same or different training groups,
c) preparing trainees for specific training with preliminary use of AR/VR technologies,
d) evaluating operational procedures in identical or different wildfire response conditions,
e) devising management and disaster management plans for hazard simulations and risk perception patterns (checked by trainees),
f) verifying emergency management and disaster management plans before a real hazard occurs,
g) rationalising the number of firefighting resources on the scene to reduce information chaos to make optimal and appropriate use of resources for the circumstances of the emergency,
h) limiting occupational risks for the trainees,
i) possibility of easy moderation of the infrastructure necessary to organise the training.

As a rule, AR/VR technologies enable simulating conditions and activities. They can combine the computational potential of computers with operational requirements reflected by the trainees. This makes it relatively easy to project wildfire response environment and operations. In addition, it should also be borne in mind that wildfire response is closely connected with other wildfire management phases (prevention, preparedness, and reconstruction and recovery). AR/VR solutions may be applied also in these contexts.

In accordance with AR/VR solutions, their application for the purposes of preparation and pre-planning activities for wildfire response may result in technology enhancement by:

a) new ideas for scenarios and virtual worlds,
b) evaluation of the existing manipulators,
c) seeking new ideas for modern manipulators adjusted to the broad spectrum of AR/VR users,
d) interesting ideas for specific manipulators (for instance communication devices, UAV pilots),
e) unique connections of standard manipulators (for example goggles and screens) with specific manipulators (nozzles, fire engines, communication devices, etc.),
f) possibilities of cooperating with experienced end-users,
g) designing user-oriented solutions.

Wildfire response determines a unique context for designing and testing virtual reality. Less potential is noticeable so far in case of augmented reality. This kind of technology requires an environment that is hard to ensure in the wildfire purposes. Preparation and pre-planning activities for wildfire response may inspire technology providers to modify the existing solutions and developing the new ones. This gains in importance when talking about manipulators and optimal ways of the technology use.

Enhancement of training-related preparation and pre-planning activities for wildfire response and the technologies needs to face certain specific limitations. The following aspects should be taken into consideration:

1) as regards preparation and pre-planning activities for wildfire response:
   a) mass scale of the incident,
   b) physicochemical mechanisms of wildfire development,
   c) numerous entities involved,
   d) high uncertainty as to weather conditions;
2) as regards Fire hazard risk assessment tools:
   a) risk of impaired balance when using AR/VR goggles,
   b) differences in manipulation abilities of trainees,
   c) stress related to the use of technology,
   d) relatively high number of information sources to be analysed,
   e) realism of the virtual world that may cause irrational behavioural patterns.

These issues may leverage training safety and require addressing specific safety issues.

6.1.4. Safety issues for the deployment of the technology

Deployment of AR/VR technology requires semi-direct contact with the trainees. This means that the trainee is connected with wildfire conditions through technological means (generally via such visualisation tools as goggles and screens). This determines specific hazards. Consequently, the following factors should be highlighted (Rączkowski, 2022):

1) Hazards of moving, loose and protruding parts.
2) Hazards associated with the movement of people.
3) Electrical shock.
4) Noise.
5) Visual radiation.
6) Biological factors.
7) Mental burden.

Examples of the circumstances connected with hazard materialisation are presented in Table 30.

Table 30. Illustrative circumstances of hazard materialisation when using AR/VT technologies in firefighter training

No.	Hazard	Illustrative circumstances
1	Hazards of moving, loose, sharp and protruding parts	a) Being hit by a manipulator. b) Being hit by a screen. c) Tripping over a platform.
2	Hazards associated with the movement of people	a) Hitting an infrastructural element (wall, chair, etc.). b) Bumping into another trainee. c) Loss of balance.
3	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to the training infrastructure (a light fixture, an electrical socket).
4	Noise	a) Noise generated by trainees. b) Noise generated in the training scenario.
5	Visual radiation	a) Radiation generated by goggles. b) Radiation generated by screens. c) Glare when removing of goggles (from a window or a light fixture).
6	Biological factors	a) Biological agents transmitted by other trainees (air ways). b) Biological agents transmitted by other trainees (manipulators and goggles). c) Biological agents accumulated on the training infrastructure.
7	Mental burden	a) Situational stress. b) Stressful competition. c) Too many sources of information (information overload).

Source: own study

As regards OSH standards, the following prevention measures may be suggested to minimise training risks related to the specified hazards:

1) for hazards of moving, loose, sharp and protruding parts:
   a) to equip the manipulator with a hand attachment cable,
   b) to firmly fix the screens (for example to walls),
   c) to mark safety distances (at least 1 m) around the training platform and other training areas,
   d) to ensure order in the training zone,
   e) to ensure support staff;
2) for hazards associated with the movement of people:
   a) to assure a trainee when executing a scenario,
   b) to mark the training areas,

   c) to mark walking paths in the training zone,
   d) to organise instruction for the use of AR/VR equipment;
3) for electrical shock:
   a) to check electrical devices before every training session,
   b) to devise safety procedures to respond to any physical damages in equipment and infrastructure;
4) for noise:
   a) to check and adjust a volume level before a training session,
   b) to organise an instruction for the use of AR/VR equipment with noise generation at a volume level typical for a scenario;
5) for visual radiation:
   a) to ensure proper illumination in the training room,
   b) to instruct trainees on how to remove goggles safely;
6) for biological agents:
   a) to disinfect the training area after every scenario,
   b) to disinfect equipment after its use,
   c) to devise a biological safety manual,
   d) to verify the health condition of every trainee;
7) for mental burden:
   a) to divide a scenario into semi-scenarios to adjust the training course to the mental potential of trainees,
   b) to minimise or eliminate competition elements from the training scenario,
   c) to ensure a friendly atmosphere during a training.

Information on these issues makes it clear that implementing appropriate solutions can be challenging while ensuring the safety of trainees. The use of the virtual world requires assuring specific conditions and may pose situations that involve stress. These two issues need to be taken into account when wanting to deliver effective training to firefighters. On the other hand, some of preventive measures are the same or at least similar to the measures applicable to other technologies and in case of different hazards. This allows optimising efforts intended to make the training safe for participants and organisers. It is especially important as many of the measures are of an organisational character.

6.2. Citizen engagement application

6.2.1. Technology in a nutshell

Citizen engagement plays a vital role in effective wildfire management, including wildfire response. This statement stems from a general community engagement model for emergency management. The model is presented in Figure 56.

Figure 56. Community Engagement Model for Emergency Management
Source: (ADRHC, 2013)

Citizen engagement uniquely combines participation, consultation, collaboration, empowerment and information. Those are core issues of effective involvement similarly as effective wildfire management. Moreover, they indicate the prevalence of wildfire response and the significant role of citizens.

Focusing on beneficiaries, the involvement seems to be the most valuable for citizens. The situation is relatively different in the case of training for firefighters. Preparation and pre-planning activities for wildfire response may be supported by citizens and/or information generated by citizens. From this perspective, firefighters should consider, analyse and support the public's response to the threat (for example by sharing information about a hazard and proper behavioural patterns). Consequently, firefighters are beneficiaries of citizen engagement but they need to effectively manage this engagement.

The main functionality of citizen engagement is to involve people in wildfire response. This may be done in multiple ways. In general, there are three groups of them:

a) to equip people with technical possibilities of informing wildfire responders and alerting other people about ascertained hazards (about a fire and any other derivative hazards),
b) to instruct people what to do if a wildfire breaks out (before, during and after the hazard occurs),
c) establishing a communication link between citizens and wildfire responders to ensure technical possibilities of crisis communication and risk communication.

Cross-referencing these groups allows specifying specific functions of the engagement in terms of wildfire response. They are as follows (Mojir et al., 2023):

1) raising awareness:
   a) informing:
      - providing instructions on how to control fires caused by negligence through personal and community information channel,
      - planning evacuation,
      - displaying alarm signs,
      - marking evacuation routes,
      - sending warnings,
      - providing guidelines for recovery after a wildfire;
   b) educating:
      - creating supportive learning environments,
      - delivering courses and training sessions,
      - implementing the concept of "coexisting with fire" to the citizens' daily life,
      - organising ludic and educational activities in nature,
      - preparing (for example by a training course) for urgent restoration of private lands and forests;
2) corresponding to attitudes (cultural values):
   a) raising engagement:
      - building a community,

  - planning of democratic participatory procedures,
  - building a network of volunteer firefighters,
  - implementing a system view on coordination of interventions,
  - raising interest in wild nature,
  - planning collaborative efforts to restore the woods after a wildfire;
 b) promoting safe practices:
  - establishing preventative behavioural patterns,
  - transforming land use into safer modes,
  - ensuring safety of infrastructure (including critical infrastructure),
  - delivering training courses and hands-on exercises in protecting health and property during a wildfire,
  - creating fire-safe landscapes;

3) shaping behaviour:
 a) assisting effective fire management:
  - facilitating the execution of self-protection measures,
  - facilitating the protection of property,
  - assisting with evacuation,
  - coordinating volunteer and professional activities,
  - collecting post-fire best practices,
  - long-term interacting with citizens for trust-building in restoration activities;
 b) taking up actions:
  - reporting hazards,
  - preventing risky behaviours.

From the practical point of view, essential functions of engagement in terms of wildfire response are deployable with the use of mobile applications (apps) (Mojir et al., 2023; Kamilaris et al., 2023)[5]. For example, when considering assisting people in wildfire conditions, apps may prove to be useful in terms of wildfire modelling, calculation of escape routes, ensuring real-time information, expanding maps, sensing of current user location and proposing alternative evacuation routes (Kamilaris et al., 2023).

Moreover, while designing citizen engagement supported by technology (including applications), it is necessary to take essential user needs into consideration. Those needs are as follows (SILVANUS D3.3, 2023):

1) "Real-time fire alerts and notifications: Citizens should be able to receive alerts and notifications about fires in their area, including the location, size and potential threat level.

[5] There are many more forms of citizen engagement (training courses, exercises, exhibitions, competitions, etc.) but apps are the most valuable owing to common access, possibility to get to almost every group of citizens, easy use and low price.

2) Map view: The app should have a map view that shows the location of fires, as well as evacuation zones and other important information and analytics.
3) Guidelines: The app should provide citizens with information on how to stay safe during a fire, including evacuation routes, shelter locations and emergency contact numbers.
4) Community engagement: The app should allow citizens to share information and updates about fires with each other, such as through a chat or forum. The app should also disseminate news regarding training activities and community events for further engagement.
5) Emergency response coordination: The app should allow coordination between citizens and emergency responders during a fire.
6) Language support for non-English speaking countries.
7) Accessibility features for visually impaired or hearing-impaired users.
8) Push notification opt-out option and other permission options: The app should allow the user to opt out from some specific features that need special phone permissions, like the draw over other apps and location sharing permission. This will, of course, limit the functionality of the application.
9) Secure & Authenticated User Management: The app should allow a safe way to sign up and log in as well as ensure that the user's personal information is handled properly".

Potential and specific forms of citizen engagement leverage ways in which citizens may be engaged in wildfire management. This determines also preparation and pre-planning activities in wildfire response and shapes the specific operational protocol.

6.2.2. Operational protocol

The universal process of wildfire response determines a background for training operational protocol for citizen engagement in wildfire response. Figure 57 presents the process. As regards the practical viewpoint on the engagement effectiveness, deployment of apps was taken into account.

The technology leverages almost all phases of wildfire response. They are early detection and communication of the hazard, effective deployment of resources to the wildfire scene, comprehensive reconnaissance of hazard situation (especially from the air), firefighting tactics, and cooperation between firefighting entities. This justifies that information from citizens can assist firefighters in almost the entire process of wildfire response. This sheds the light on mobile technologies' implementation to firefighting training. Examples on how to implement citizen engagement into training activities for particular response phases are presented in Table 31. These ways allow of operationalising protocols of technology use for firefighting training purposes.

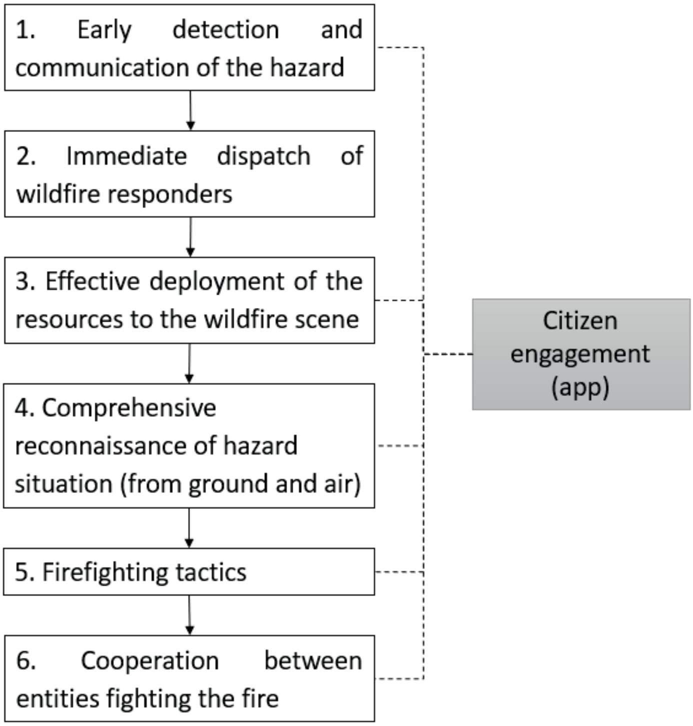

Figure 57. Role of citizen engagement in support of wildfire response training

Source: own study

Table 31. Examples on how to implement citizen engagement app into particular phases of wildfire response

No.	Phase	Examples
1	1. Early detection and communication of the hazard	1) Trainee monitors the situational picture and identifies potential hotspots. 2) Trainee confirms detection of a hazard in a specific area on the basis of information from citizens. 3) Trainee verifies the reliability of information concerning hazard occurrence. 4) Trainee marks a preliminary zone where a wildfire has occurred based on information from citizens. 5) Trainee shares information concerning a hazard with citizens in the danger zone.
2	3. Effective deployment of the resources to the wildfire scene	1) Trainee adjusts the arrival route to the wildfire scene with respect to the location of hotspots and the general situation on roads (traffic jams, high density of traffic, information about road accidents, etc.).

Table 31 cont.

No.	Phase	Examples
		2) Trainee seeks alternative directions and arrival routes in case the wildfire and/or traffic develop. 3) Trainee formulates guidelines for citizens to optimise their evacuation from the danger zone.
3	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee analyses the wildfire scene from the perspective of a citizen to complete the situational picture. 2) Trainee analyses information generated by citizens to collect basic reconnaissance information seeking grounds for situational development and derivative threats. 3) Trainee analyses the wildfire scene from the perspective of a citizen to collect basic reconnaissance information related to people in need of help (for example in evacuation circumstances).
4	5. Firefighting tactics	1) Trainee marks the preliminary range of a danger zone for further planning of firefighting tactics. 2) On the basis of citizens' perspective, trainee monitors the progress of the firefighting operation and checks its effectiveness in accordance with tactical orders. 3) Trainee identifies threats that may affect firefighters. 4) Trainee formulates guidelines for citizens to optimise total efforts related to wildfire response (to ensure that citizens do not impede the firefighting action and firefighters do not affect the evacuation of people).
5	6. Cooperation between firefighting entities	1) Trainee marks the danger zone for further planning of cooperation between firefighting entities. 2) Trainee monitors proceeding of overall response operation and checks it due to tactical orders and disaster management standards. 3) Trainee identifies threats that may affect citizens and firefighting entities. 4) Trainee indicates evacuation posts for citizens and informs them about their location.

Source: own study

Examples on how to implement citizen engagement app into particular phases of wildfire response constitute general operational protocol of citizen engagement for firefighting training.

Focusing on the specific operational protocol, the use of citizen engagement solutions in wildfire response training is based on the following operational activities:

1) Familiarisation with the training scenario.
2) Raising awareness about functionalities of the citizen engagement tool (app).

3) Instruction for proper use of citizen engagement tool or obtaining support from a trainer (the tool operator).
4) Pre-training use of citizen engagement tool on a semi-scenario (elements of training scenario) to find out kinds of information that may be obtained from the tool.
5) Basic use of citizen engagement tool to execute the training scenario (directly by a trainee or indirectly with the support of a trainer).
6) Debriefing after the training and training evaluation.

It is worth highlighting that the use of the citizen engagement tool in firefighting training comes down to the use of a kind of dashboard that visualises the engagement results rather than direct involvement of citizens. This is justified by safety reasons. Citizens may be involved in the training activities but their involvement must be under strict safety conditions. This dashboard operator perspective stems from the specific operational protocol.

6.2.3. Enhancement capabilities

Citizen engagement is valuable for firefighting training because it allows gaining a unique perspective of a person present in a danger zone. It may often provide more information for wildfire response managers than information collected only by firefighters. This issue determines both enhancement capabilities for the training effectiveness and directions for further technology development.

As far as training-related preparation and pre-planning activities for wildfire response are concerned, the application of citizen engagement tools allows significant enhancement by:

a) focusing attention of training participants on the areas characterised by the highest fire risk,
b) using societal perspective as determinant of decisions to be made during a training course,
c) operationalising emergency management and disaster management plans with respect to citizens' response to a hazard,
d) adjusting overall wildfire response efforts to information collected by citizens and societal behavioural patterns recorded in the danger zone,
e) analysing wildfire (disaster) risk associated with societal response to a hazard and citizens' security,
f) basing on real case studies,
g) pre-defining societal-related aspects of a situational picture and implementing them into the training scenario.

Many people visit the woods for multiple reasons. The use of citizen engagement tools allows rationalising firefighting training from this point of view. The tools are sources of information for creating a picture of the situation as well as to plan and conduct response activities. This demonstrates that implementing the citizen engagement tool in the training ensures the training adequateness to current societal determinants.

As regards citizen engagement tools, their application for the purposes of preparation and pre-planning activities for wildfire response may enable technology enhancement by:

a) inspiring to devise new functionalities to gather information,
b) integrating these tools with geospatial information systems (GIS) to easily visualise results of the processes of information collection,
c) combining the tools with decision support systems,
d) adjusting to user requirements, needs and expectations (designing user-oriented solutions).

Confronting citizen engagement tools with their users during a training course is, as a rule, beneficial as it enables their practical validation. Hearing the opinions of users may be also very inspiring with respect to technology development. This is becoming increasingly important nowadays as new technologies develop and appropriate improvements are a challenge for the specific product supplier.

As regards enhancement limitations, they are noticeable mainly in the case of tools. The following aspects should be taken into consideration (Mojir et al., 2023):

a) acceptance of citizen engagement tools by the general public (who are reluctant to install a tool),
b) infrequent appearance of local citizens in an afforested area,
c) reluctance of the tool owners to share data,
d) false-positive or malicious fire reports,
e) unavailability of Internet connection in the afforested areas.

These issues leverage the training effectiveness. They may be dealt with as organisational challenges to be faced when organising training efforts for pre-planning and preparation activities in wildfire response. However, in the given context the main focus is on training attendees – firefighters. This is why relevant limitations can be minimised thanks to pre-collected data and generalisation of training scenario assumptions.

6.2.4. Safety issues for deployment of the technology

Deployment of citizen engagement solutions entails an indirect contact with the trainees. That training attendee (a firefighter) is connected with the wildfire scene using technological means (generally via such visualisation equipment as a screen). This determines specific hazards. From the training safety viewpoint, the following factors should be highlighted (Rączkowski, 2022):

1) Hazards associated with movement of people.
2) Electrical shock.

3) Visual radiation.
4) Biological factors.
5) Mental burden.

Table 32 presents examples of the hazards' materialisation circumstances.

Table 32. Illustrative circumstances of hazard materialisation when using fire hazard risk assessment tool in firefighter training

No.	Hazard	Illustrative circumstances
1	Hazards of moving and loose, and protruding parts	a) Being hit by a screen. b) Stumbling over a computer post. c) Tripping over a cable.
2	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to the training infrastructure (a light fixture, an electrical socket).
3	Visual radiation	a) Radiation generated by screens.
4	Biological factors	a) Biological agents transmitted by other trainees (air ways). b) Biological agents accumulated on the training infrastructure.
5	Mental burden	a) Situational stress. b) Stressful competition. c) Too many sources of information (information overload). d) Inability of using the assessment tool.

Source: own study

Training risks may be minimised if the following prevention measures are taken into account:

1) for hazards of moving, loose, sharp and protruding parts:
   a) to fix firmly the screens and cables (for example to walls),
   b) to mark safety distances (at least 1 m) around the training platform and other training areas,
   c) to ensure order in the training zone;
2) for electrical shock:
   a) to check electrical devices before every training,
   b) to devise safety procedures to respond to any physical damages in equipment and infrastructure;
3) for visual radiation:
   a) to ensure proper illumination in the training room;
4) for biological agents:
   a) to disinfect the training area after every scenario,
   b) to disinfect equipment after its use,

   c) to devise a biological safety manual,
   d) to verify the health of every trainee;
5) for mental burden:
   a) to minimise or eliminate competition elements from the training scenario,
   b) to ensure a friendly atmosphere during a training course,
   c) to ensure that staff members support trainees in technical use of the assessment tool (including support in proper interpretation of the assessment results).

Implementation of solutions based on citizen engagement is characterised by a low level of occupational risk. It is typically an office job (even if it takes place in field conditions). It comes down to carrying out cognitive analyses and work on an IT dashboard. Consequently, it may be done in almost all kinds of wildfire response training courses.

6.3. IT Dashboard

6.3.1. Technology in a nutshell

Many technological solutions that facilitate wildfire management (including response to the hazard) are dashboard-related. This means that computational models, calculation mechanisms and detection functionalities are typically technical solutions. To make them operational for firefighters, there is a need to visualise the computation, calculation and detection results on a screen or on another visualisation device. This is of great importance for the purposes of response initiation, planning and coordination.

Main beneficiaries of the IT dashboard are trainees who use other technological solutions to support wildfire response. Special attention is paid to disaster managers, disaster analytics (for example in disaster management centres), and field firefighters. They determine the most information-related groups of stakeholders.

Figure 58 shows an illustrative IT dashboard to be used for wildfire management purposes, including multi-entity wildfire response operations.

In general, the presented dashboard comprises three essential elements:

a) a map,
b) a set of layers,
c) pins.

The map is the most important element from the viewpoint of making the dashboard operational for firefighters. Its resolution and level of detail must meet operational expectations of end-users. It is worth ensuring access to geospatial

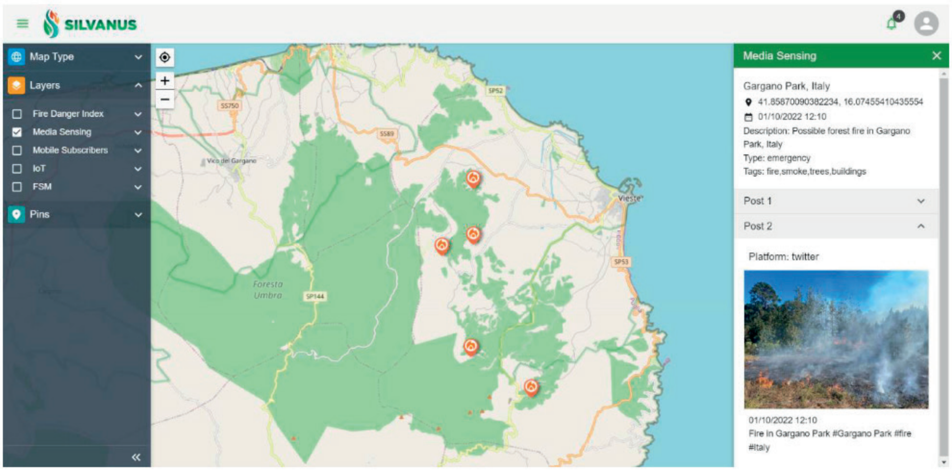

Figure 58. IT dashboard to be used for wildfire management purposes, including multi-entity wildfire response operations
Source: (SILVANUS D4.2, 2023)

information for all elements that may determine the situational picture, including (i.a.):

a) secondary threats,
b) network of roads,
c) natural barriers for the fire,
d) potential defence lines,
e) evacuation zones,
f) other elements.

It is highly desirable to ensure access to a map with the use of GIS. This allows carrying out geospatial analyses and providing additional information to decision makers.

A set of layers corresponds to the number of functionalities integrated to the dashboard. Their use should be intuitive and relatively easy for trainees after their preliminary introduction to the technology. The result of the functionality use needs to be unambiguously interpretable and highlighted on a screen. This may comprise the following (i. a.):

a) detection of hot spots,
b) marking the danger zone (according to such fire manifestations as flames and smoke),
c) forecasting hazard development,
d) direct observation of the wildfire scene,
e) showing personal field reports,
f) planning defence lines on the basis of natural and/or artificial fire barriers,

g) marking places where citizens need evacuation,
h) geo-locating firefighting entities (especially fire trucks and reconnaissance equipment),
i) pointing out infrastructure the presence of which in the danger zone may pose inherent derivative threats (including critical infrastructure, chemical industries, landfills).

The SILVANUS dashboard (SILVANUS, 2024) is a good example on how to integrate GIS background with technology solutions that support firefighters in wildfire response (Orzechowski et al., 2023). Every functionality has its representation on the map and is represented by a specific layer. The following layers have been preliminarily developed: Fire Danger Index, Media Sensing, Mobile Subscribers, IoT, Fire Spread Model (FSM) and Pins (i.e. information presented and geo-located with the use of social media solutions). Figure 59 presents a view of the SILVANUS dashboard.

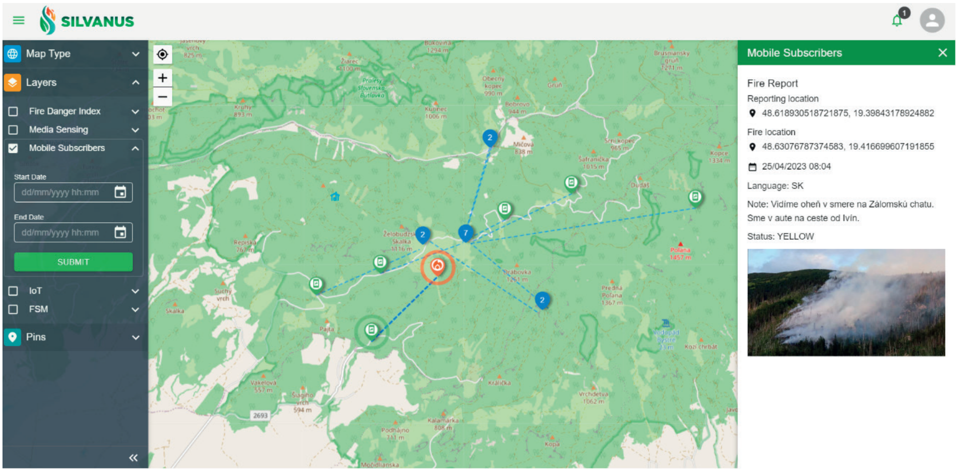

Figure 59. View of SILVANUS dashboard

Source: own study

Possibility of integrating different software, communication and computational solutions is an evident advantage of the IT dashboard. This may significantly enhance the overall functionality of technological solutions also in terms of training for firefighters handling wildfires.

6.3.2. Operational protocol

The IT dashboard has the potential to integrate practically all functionalities that support preparation and pre-planning activities in wildfire response with respect to firefighter training. For this reason, the specific operational protocol can cover all phases of the response. Figure 61 presents the response process and highlights relationships between the IT dashboard and the response phases.

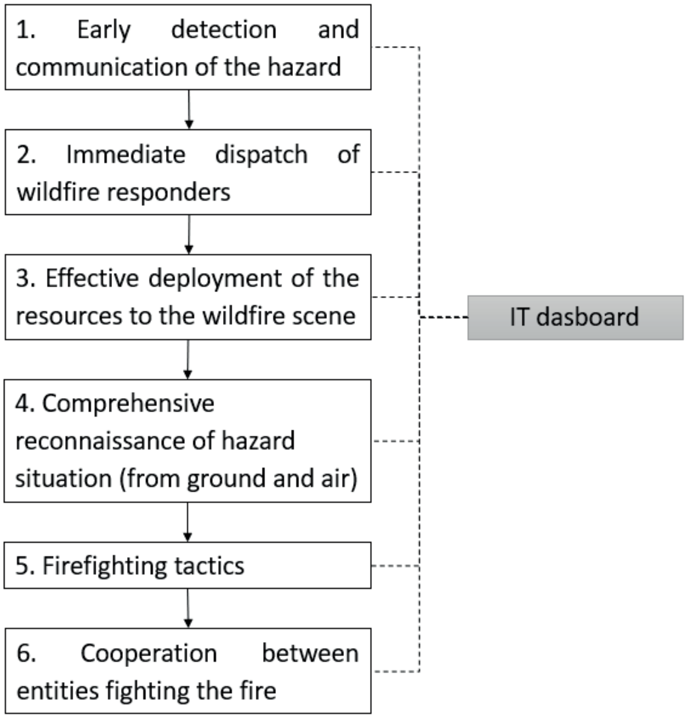

Figure 60. Use of IT dashboard in support of wildfire response training
Source: own study

The technology impact concerns detection and communication of the hazard, immediate dispatch of wildfire responders, effective deployment of resources to the wildfire scene, comprehensive reconnaissance of the hazard situation (from the ground and from the air), firefighting tactics and cooperation between firefighting entities. Those are wildfire response phases in which integration of multiple functionalities and their representation on a map are crucial from the perspective of wildfire response training. Examples on how to use the IT dashboard in particular phases are presented in Table 33. As a rule, the examples are derivatives of particular functionalities and refer to them, either directly or indirectly. This is especially noticeable in cases of computational solutions (for instance assessing the fire danger index, forecasting the fire development). Their practical use in a training course is impossible without some kind of a dashboard.

Table 33. Examples of using the IT dashboard in particular phases of wildfire response

No.	Phase	Examples
1	1. Early detection and communication of the hazard	1) Trainee indicates the most probable places where a wildfire may occur. 2) Trainee indicates hotspots. 3) Trainee analyses the riskiest areas according to reconnaissance results (from the air and/or from the ground). 4) Trainee forecasts the riskiest areas in multiple weather conditions. 5) Trainee sends fire alerts to citizens.
2	2. Immediate dispatch of wildfire responders	1) Trainee makes first selection of firefighting resources to be deployed on the wildfire scene. 2) Trainee formulates dispatch information to wildfire responders – the information that answers the following questions: what?, where?, who?, how?, why?, what for? 3) Trainee initiates the dispatch process with the use of a dashboard. 4) Trainee shares a dashboard or a print from a dashboard with wildfire responders at the stage of dispatch. 5) Trainee supplements the first operational picture with information about wildfire responders being dispatched.
3	3. Effective deployment of the resources to the wildfire scene	1) Trainee points out arrival routes to the wildfire scene. 2) Trainee adjusts the arrival route to the wildfire scene based on wildfire risk. 3) Trainee seeks alternative directions and arrival routes in case the wildfire develops as reflected by relevant risk. 4) Trainee seeks alternative directions and arrival routes in case the wildfire and/or traffic develop. 5) Trainee formulates guidelines for citizens to optimise their evacuation from danger zone.
4	4. Comprehensive reconnaissance of hazard situation (from the ground and from the air)	1) Trainee analyses the wildfire scene from the air and/or from the ground perspective to collect basic reconnaissance information about the fire and the related risk. 2) Trainee indicates places to operate UAVs/UGVs in wildfire conditions (as a rule outside the riskiest areas and on the path of hazard development). 3) Trainee indicates places to operate UAVs/UGVs in wildfire conditions (as a rule near to the fire flanks). 4) Trainee analyses information generated by citizens to collect basic reconnaissance information seeking grounds for situational development and derivative threats. 5) Trainee analyses the wildfire scene to find places that could be in danger in the given time horizon.

No.	Phase	Examples
5	5. Firefighting tactics	1) Trainee marks the danger zone for further planning of firefighting tactics. 2) Trainee plans defence lines, concentration points for firefighting resources, water supply lines and evacuation routes. 3) Trainee monitors the progress of the firefighting operation and checks it taking into account tactical orders. 4) Trainee identifies threats that may affect firefighters. 5) Trainee indicates the most probable direction of hazard development.
6	6. Cooperation between firefighting entities	1) Trainee indicates a place to gather firefighting resources (outside the riskiest areas of the wildfire scene). 2) Trainee marks zones for water drop for fire suppression from the air. 3) Trainee indicates locations to use UGVs to extend the radio communication range. 4) Trainee indicates locations to use UGVs to build firefighting posts. 5) Trainee communicates with other trainees to exchange operational information related to the situational picture and hazard development.

Source: own study

Application of the IT dashboard in wildfire response training is based on general operational activities. They can be combined into a general protocol as follows:

1) Familiarisation with the training scenario.
2) Instruction for proper use of the IT dashboard or to get support from a trainer (the dashboard operator).
3) Pre-training use of the dashboard in a semi-scenario (elements of training scenario) to find out kinds of information that that may be obtained from it and to manually check the dashboard functionalities.
4) Basic use of the IT dashboard to carry out the training scenario (directly by a trainee or indirectly with the support of a trainer).
5) Debriefing after the training and training evaluation.

The general operational protocol can be detailed with reference to particular operational protocols for functionalities integrated to the dashboard. The training organiser should decide on the level of generality for activities to be executed by the trainees. The level of generality is the basic reference in planning the use of the IT dashboard for training purposes.

6.3.3. Enhancement capabilities

When using multiple technology functionalities to train firefighters, it is advisable to gather all information sources to create a picture of the situation in a single place. The operational simplification is crucial in this context due to wildfire response specifics (a lack of time, the need to collect and visualise geo-information, focusing on good operational practices, situational stress, technical limitations on wildfire scene, etc.).

The use of the IT dashboard in firefighter training allows certain enhancement capabilities. Such enhancement is applicable both to the training and the supporting technologies.

In accordance with the training-related preparation and pre-planning activities for wildfire response, the use of a IT dashboard allows achieving significant enhancement by (i. a.):

a) using updateable situational picture as a background for making decisions,
b) focusing the attention of trainees on areas characterised by the highest risk of fire and its development,
c) determining the training scenario and the training procedure by information visualised on a dashboard,
d) rationalising the allocation of firefighting resources,
e) permanent monitoring of wildfire response,
f) operationalising emergency management and disaster management plans for risk of fire development (including the cascading effect of a wildfire),
g) automating the fire detection processes,
h) shortening wildfire management processes,
i) basing on real case studies.

The IT dashboard plays a significant technology integration role. For this reason, it can be the basic tool to determine the situational picture and to implement the training scenario. Its deployment in training processes may shorten the duration of those processes. Furthermore, it may cover the complexity of the response. These two aspects significantly affecting the training effectiveness. Consequently, the dashboard may enhance the effectiveness.

Focusing on technology related to IT dashboard, its deployment in firefighter training can prove to be valuable for the enhancement of technology. The following illustrative improvements have been recorded:

a) inspiration for the development of a new map view presented by the dashboard,
b) adjusting of labels to end user needs,
c) in-depth integration of GIS solutions with computing solutions,
d) new ideas for GIS analyses referring to information presented on the dashboard,

e) designing user-oriented functionalities to be visualised on the dashboard,
f) technological and technical integration of a dashboard to decision support systems of wildfire responders,
g) transmission of dashboard output to personal devices on the wildfire scene,
h) sharing access to a dashboard with different wildfire responders,
i) carrying out computations in a virtual cloud.

The training offers a good possibility to confront a dashboard with potential beneficiaries. Consequently, the technology provider will be able to verify technical solutions in practice and also to collect user requirements and feedback. In addition, in this case the core issue is the operational picture. As regards the specifics of preparation and pre-planning activities in wildfire response, it should be the common operational picture, to make sure that every wildfire responder uses the same background and interprets the situation in the same way as other responders.

The enhancement entails several limitations. The following aspects should be taken into account:

a) limited access to data,
b) need of integrating technologies as well as technical tools, solutions, etc.
c) necessity of upgrading visualisation tools,
d) differences in dashboard manipulation abilities of the trainees,
e) stress related to the use of a dashboard,
f) difficulties in proper interpretation of dashboard visualisations,
g) a relatively high number of information sources to be analysed.

Knowledge concerning the limitations may be helpful in implementing the IT dashboard to the training processes. On the one hand, this implementation may significantly improve the training effectiveness in the scope of preparation and pre-planning activities in wildfire response. On the other hand, some effort is needed to adjust dashboard solutions to specific requirements of a training course.

6.3.4. Safety issues for deployment of the technology

A trainee(a firefighter) is connected to the wildfire scene indirectly with the use of technological means (generally via such visualisation equipment as a screen). This gives rise to specific hazards. From the training safety viewpoint, the following factors should be highlighted (Rączkowski, 2022):

1) Hazards associated with the movement of people.
2) Electrical shock.
3) Visual radiation.
4) Biological factors.
5) Mental burden.

Table 34 presents examples of circumstances of hazard materialisation.

Table 34. Illustrative circumstances of hazard materialisation when using IT dashboard in firefighting training

No.	Hazard	Illustrative circumstances
1	Hazards of moving, loose, and protruding parts	a) Being hit by a screen. b) Stumbling on a computer post. c) Tripping over a cable.
2	Electrical shock	a) Physical damage to the computing equipment. b) Physical damage to the training infrastructure (a light fixture, an electrical socket).
3	Visual radiation	a) Radiation generated by a screen.
4	Biological factors	a) Biological agents transmitted by other trainees (airways). b) Biological agents accumulated on the training infrastructure.
5	Mental burden	a) Situational stress. b) Stressful competition. c) Too many sources of information (information overload). d) Inability of proper interpretation of the dashboard output.

Source: own study

Following prevention measures are understood as basic ways to reduce training risks related to the use of IT dashboard:

1) for hazards of moving and loose, sharp and protruding parts:
    a) to fix firmly the screens and cables (for example to walls),
    b) to mark safety distances (at least 1 m) around training platform and other training areas,
    c) to ensure order in the training zone;
2) for electrical shock:
    a) to check electrical devices before every training,
    b) to devise safety procedures to respond to any physical damage in equipment and infrastructure;
3) for visual radiation:
    a) to ensure proper illumination of the training room;
4) for biological agents:
    a) to disinfect the training area after every scenario,
    b) to disinfect equipment after its use,
    c) to devise a biological safety manual,
    d) to verify the health condition of every trainee;
5) for mental burden:
    a) to minimise or eliminate competition elements from the training scenario,

b) to ensure a friendly atmosphere during a training course,
c) to ensure that staff members support trainees in the technical usage of a dashboard (including support in proper interpretation of the dashboard output).

The use of an IT dashboard entails a relatively low level of occupational risk (in comparison, for example, with activities executed in field conditions). It is typically an office job (even if it takes place in field conditions). It comes down to making cognitive analyses and interpreting the output from solutions integrated to the dashboard. Moreover, it may be done in almost all kinds of wildfire response training.

Conclusion

Training for firefighters plays a primary role in becoming prepared to wildfire response. New technologies are deployed to enhance the training addressed at fire service in wildfire response. Employing those technologies in the training processes may raise the effectiveness of educational activities, automate some of the operational tasks, minimise risks related to making potentially irrational decisions, and improve the personal safety level of the trainees. As regards wildfire response, the use of new technologies is seen as an opportunity for enhancing the effectiveness of firefighting operations through early detection and communication of the hazard, immediate dispatch of wildfire responders, effective deploying of resources to the wildfire scene, comprehensive reconnaissance of the hazard situation (from the ground and from the air), firefighting tactics, and cooperation between firefighting entities. This means the potential to positively ensure firefighter safety, create situational awareness and support fire systems.

The SILVANUS project provides a basis for how to use new technologies to improve fire brigade training in fire response in a comprehensive and integrated way. The project is focused on a unique combination of wildfire management solutions and tools, and the development of an integrated technological and information platform. The SILVANUS approach bases on close alignment of wildfire management organisation, technosphere, and societal involvement. It specifies that wildfire management involves three essential phases – Phase A (prevention and preparedness), Phase B (detection and response), and Phase C (restoration and adaptation), which strongly corresponds to general disaster management process. Wildfire response ascribes into Phase B. Because all the phases are interrelated, many SILVANUS solutions and tools are deployable to wildfire response and, consequently, to training of firefighters. This may be done directly (by the use of technologies to support firefighting entities) or directly (with support in decision-making and an in-depth analysis of wildfire conditions and determinants).

In accordance with SILVANUS technologies, the following solutions and tools may be applied in wildfire response:

1) detection technologies:
    a) fire detection using IoT devices,

   b) fire detection at the Edge,
   c) fire detection by social sensing;
2) computational tools:
   a) biodiversity profile mobile app,
   b) fire danger risk assessment,
   c) fire spread forecast;
3) end-technology tools:
   a) fire monitoring using UAVs (drones),
   b) use of UGVs (robots),
   c) Forward Command Centre,
   d) MESH-in-the-Sky;
4) decision support systems:
   a) Multilingual Forest Fire Alert System,
   b) Resource Allocation of Response Teams,
   c) Priority Resource Allocation based on Forest Fire Probability,
   d) Evacuation Route Planning;
5) societal involvement tools:
   a) augmented reality / virtual reality training for firefighters,
   b) citizen engagement application,
   c) IT Dashboard.

They reflect the current state-of-the-art of technology maturity, development and development trends. Depending on their specific characteristics and operational advantages, those technologies can be classified as detection technologies, computational tools, end-technology tools, decision support systems, and societal involvement tools. Classification results correspond to general functionalities that are valuable from the viewpoint of firefighters when considering wildfire response. The results also indicate potential areas for the use of technologies in training for firefighters.

Particular technologies differ from each other given their form, complexity, potential for integration to other technologies (for example IoT devices and robots), and practical implementation issues. As regards the latter ones, the most significant issues seem to be price and deployment efforts. They correspond to specifics of wildfire response (urgency, difficult terrain, communication difficulties, etc.) and organisation of fire protection in particular countries.

In terms of the financial aspects of using the technology, it seems that robots, detector kits (one detector is insufficient to cover a large area in the forest), firefighting drones (because sensors can be installed on smaller drone structures), detection drones (because of the deployment of expensive sensors) and a collateral command centre are the most expensive. In turn, the current state of technology development makes communication tools (such as MESH-in-theSky) and decision support systems (typical IT functionalities) reasonably and accessibly priced.

Computational tools require access to data as well as data and visualization tools that may significantly determine the total price for implementation of relevant technologies (the technologies are not stand-alone and technically independent from other solutions, for example GIS). In addition, extensive monitoring of social media gives new, effective and relatively cheap possibilities to deploy social media sensing to the practice of wildfire response. The higher the implementation price, the harder a broad use of the technologies during a training course.

The next important issue are efforts connected with deployment. As a rule, less effort is required in the case of stand-alone solutions (for example camera-equipped drones without any additional sensors). In such a case financial aspects are primary determinants. However, the operational potential increases when some of the technologies become integrated. This is very important when talking about sensors. Sensing tools have one more significant disadvantage. Their potential can be noticeable when sensors cover the entire area in the woods or at least the high risk area. It is relatively simple in case of small countries but it is not for the biggest ones (Canada, USA, Australia, etc.). Due to their sensing abilities, dozens, hundreds or even thousands of sensors are required to achieve the detection targets. Furthermore, sensors must be deployed before a fire occurs to detect hazard materialisation. This requires direct operational activities and lowers demand on sensors in training processes. Once again, social sensing and citizen engagement tools are considered to be technologies with the highest implementation potential.

In answering the question of what approach allows new technologies to be implemented effectively and comprehensively to improve fire service training in fire response, selected SILVANUS technologies can be used for this purpose. The research results prove that specific implementation requires considering the specifics of the technologies(so called 'technologies in a nutshell'), operational protocols on how to use the technologies for the training, as well as reflecting two essential viewpoints for enhancement (the perspective of firefighters and the point of view of technology providers), as well as personal safety issues. Consequently, the set of specific information concerning the implementation aspects is presented. The information considers maturity of technologies, reflects operational needs and expectations of firefighters, indicates particular enhancement capabilities in the two perspectives – the perspective of firefighters and the viewpoint of technology providers, and precise guidelines on how to minimise personal risks for trainees when deploying new technologies in training for firefighters. This determines the comprehensive approach to the use of new technologies in enhancing training for fire service in wildfire response, proves achievement of the research objective, and confirms veracity of the research hypothesis.

The research was strongly focused on the fire service. This determined the set of activities to be supported by new technologies. However, the fire service is the primary albeit not the only wildfire responder. When considering the future research stemming from the executed research, certain specific directions may take into account other wildfire responders such as the forest service, public administration, armed forces, non-governmental organisations, and foreign entities (for example entities constituting Forest Fire Fighting modules of the Union Civil Protection Mechanisms, and firefighting resources from neighbouring countries). Even if wildfire response activities have generally the same objectives, operational strengths and weaknesses, needs and expectations may differ in case of specific services, inspections, guards, forces, troops and public administration bodies. This fact identifies a promising research direction for the future in order to make the existing research complete in the perspective of the overall wildfire response, and not only selectively for the fire service.

Another research limitation was the direction of training activities. Training may not fully reflect operational conditions of wildfire response. Real conditions may pose direct danger to human life and health and also generate serious losses to property and environment. This is the reason why training courses are organised to minimise personal risks for firefighters during the execution of quasi-real response activities, and to reduce other risks related to a wildfire. Consequently, it becomes necessary to check out the technologies in real wildfire response conditions. This requires implementing them into the fire service technosphere and to precede them by training.

The last significant limitation was applying the SILVANUS set of solutions and tools. They were selected on the basis of the state-of-the-art current maturity level and development trends of technologies from around the world. In line with project activities and respecting the point of wildfire response, the solutions and tools were tested during a set of technology demonstrations conducted in Australia, Croatia, the Czech Republic, France, Greece, Indonesia, Italy, Portugal, Romania and Slovakia. They reflect the technology potential for 2024. As technologies continue evolving, there is a practical need to monitor them and verify new advantages and operational possibilities to apply the tools and the solutions to the training of firefighters in next timeframe (for example in 3 years). It is important to keep up to date and to seize opportunities related to new technologies in enhancing the training for fire service in wildfire response.

In conclusion, training for firefighters seems to be a good opportunity to verify solutions and tools in practice and to confront them with end-users – their needs, expectations, manual and cognitive abilities, as well as biases. It is typically challenging for both the trainees and the technology providers. However, training is essential to practically verify whether a technology is really useful in the given context. It may also result in firefighters raising their awareness and identifying directions for new technologies. This means that the benefits can be two-sided and synergistic effect may be generated. Preparation and pre-planning activities for wildfire response may become even more effective.

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