The SILVANUS Handbook on Systematic Methodology for the Preparation and Pre-planning Activities for Wildfire Response

Pawel Gromek & Anna Szajewska (Eds)

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This monograph contains the results of scientific research carried out within the framework of the international research and development project entitled Integrated Technological and Information Platform for Wildfire Management (SILVANUS, grant number 101037247), co-implemented by Fire University (the Main School of Fire Service) in the years 2021–2025 within the Horizon 2020 programme.

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Introduction

Wildfire is one of disaster triggers worldwide (UNISDR, 2017). It shapes global, regional and national safety and security environment just like floods, strong winds, droughts, tsunamis, earthquakes, chemical spills, industrial accidents, epidemics, etc. (GAR, 2022). Its specific manifestations (flames, smoke, thermal radiation) may cause direct danger to human life and health. Furthermore, wildfire occurrence is said to be an initiating factor for such multiple derivative threats as heat wave, biodiversity loss, deforestation, forest decline and extinction, forest disturbance, failure of supply system, explosion, another fire, blackout, social unrest, environment degradation, etc. (UNDRR-ISC, 2021). It is especially noticeable when critical infrastructure and human settlements are in the danger zone and flames, smoke and thermal radiation affect people, animals, property, infrastructure and the natural environment. The significance of wildfires is gaining in importance due to climate change and military conflicts (for example in Ukraine, Russia and the Middle East at the time of book drafting).

Complex determinants of a wildfire leverage the complexity of wildfire response. Different countries have worked out a number of concepts on how to face this kind of a hazard and the concepts reflect regionally wildfire determinants and specific response conditions (Majlingova et al., 2022; OCHA, 2024). In general, the response is the operational domain of fire service, forest service, armed forces, public administration, non-governmental organizations and other institutions and organizations that are both capable and willing to protect the woods against a fire. Their close and effective cooperation is crucial to cope with a wildfire and to limit severe consequences for humans, property and the environment. Multi-entity cooperation is a core issue of wildfire response because of the mass effect of hazard development and its dynamics. Accordingly, fire service often conducts direct extinguishing actions from the ground with the involvement of state and voluntary troops, is supported by forest service that shares its knowledge of forests and its firefighting and reconnaissance equipment, may rely on armed forces, border guard and police troops in performing fire extinguishing water discharges (from helicopters) and reducing derivative treats, use drone operators to carry out reconnaissance activities, with coordination of public administration. Even if the fire service is the primary wildfire responder, it is hard to expect that firefighters put out the fire without any help from other safety and security entities. This highlights the necessity of preparing an entire spectrum of responders for and pre-plan response to a wildfire comprehensively and with openness on the cooperation in different dimensions, aspects and disaster management phases.

Another issue that affects preparation and pre-planning activities for wildfire response is the progressive implementation of new technologies to support fire service and its co-operators. It seems to be a natural consequence of technology development in general. As far as firefighting and rescue operations are concerned, the development is reported in case of, for example, Artificial Intelligence (AI), electric fire trucks, augmented and virtual reality (AR and VR) and scheduling and workforce management software (inTime, 2024). The more specific ones are drones (Unmanned Aerial Vehicles, UAVs), robots (Unmanned Ground Vehicles, UGVs), fleet integration, AI, electric vehicles and equipment, VR, automated medicine documentation, seamless data transmission and automated real-time call tracking (Emergent, 2024). Some of them find application specifically in wildfire response. They include AR/VR training for firefighters, fire danger risk assessment, fire detection based on social sensing, fire detection from the devices of Internet of Things (IoT), fire monitoring at the Edge, fire inspection using UAVs, fire spread forecast, biodiversity profile mobile app, citizen engagement app, decision support system on resource allocation of response teams, health impact assessment, evacuation route planning, integrated data insights, forest fire alert system, priority resource allocation, deep learning model for wildfire severity prediction, IT dashboard and MESH-in-the-Sky (SILVANUS, 2024). Technology development forces the fire service to streamline operational procedures and reflect modern technological solutions in training protocols to maximise the preparation effect to hazard situation (Fuente et al., 2024).

As every country and, even, community may have its own idea concerning preparation and pre-planning activities for wildfire response, training seems to be the universal and organisationally flexible manner in this context regardless of country, community, operational standards, technologies accessible, infrastructure affected, etc. (Gromek, 2021; Fonio et al., 2023). Other preparation and pre-planning activities are regionally and locally determined but training may reflect all wildfire response determinants. It is especially important to shape international abilities to face a wildfire because common efforts of wildfire responses from different countries require the common understanding of wildfire phenomenon and operational standards. Training can help to implement relevant knowledge as well as develop good practices and deploy modern technologies (firstly to training protocols, and secondly to the practice of wildfire response) (Fonio et al., 2023; Zwęgliński, 2023).

The complexity of the wildfire phenomenon and the relevant response activities, the need to consider regional and local determinants, and the multitude of supporting technologies justify the systematic development of fire response training (Heikkila et al., 2010; Teie, 2018; Majlingova et al., 2022). This suggests that training organisation should be preceded by in-depth analyses of a wildfire – the phenomenon and the response, as well as specifics of training related to preparation and pre-planning activities for wildfire response. It should be based on compiling information on methodological basics of the training (training objectives, forms, methods and materials) and technology analysis. The final outcome should be training protocols that bring all these issues together into a comprehensive and integrated curriculum. Following these issues provides a foundation for developing a systematic methodology for the preparation and pre-planning activities in wildfire response.

A review of the literature and available information sources does not confirm that the body of knowledge considering the issues above has been developed. Existing information sources focus primarily on relatively separated aspects of such training (for example reconnaissance, firefighting tactics, safety issues), only basic information on the wildfire phenomenon and the response, or particular technologies (for example UAVs, UGVs, IT systems, communication solutions). In turn, an analysis of training protocols does not provide an answer to the question on what cognitive foundations they had been elaborated ("previous experience and good standards" seem to be an inappropriate and overly general answer to replicate and evaluate such a training in the future). Consequently, it was reasonable, cognitively necessary and practically desirable to address this knowledge gap.

The research problem was to answer the following question: What systematic methodology allows to prepare and pre-plan activities for wildfire response? It reflected the assumed research objective, and namely to develop a systematic methodology to prepare and pre-plan activities for wildfire response. It was assumed that the systematic methodology should be in line with the specifics of wildfire phenomenon and response, the specifics and methodological basics of such of training, and take modern technologies into consideration. From the operational point of view, it needs to be reflected in training protocols.

The above-mentioned methodological assumptions directly correspond to task T3.3 of preparation and pre-planning activities for wildfire response in the international research-development project on the integrated technological and information platform for wildfire management (cryptonym ‘SILVANUS’). The project has received funding from the European Union Horizon 2020 research and innovation programme under grant agreement 101037247. This monograph reports part of the research results compiled during the execution of this task and presents these results structurally tailored to the methodological assumptions.

Chapter 1 provides the background for an in-depth analysis on preparation and pre-planning activities for wildfire response. It addresses the specifics of a wildfire, with special attention paid to its phenomenon and response. The definition and causes of a wildfire have been described. Conditions for the origin and development of this hazard were presented. Information on wildfire types facilitates comprehending typical hazard conditions and development patterns. The process of wildfire response covers all types of wildfires and reflects typical kinds of activities necessary to address the hazard under consideration.

Chapter 2 focuses on training related to preparation and pre-planning activities for wildfire response. The training is said to be universal and sufficiently organisationally flexible to cover these activities in line with specifics of wildfire phenomenon and response, the specifics and methodological basics of a training course, as well as modern technologies accessible to wildfire responders. A presentation was provided of training needs. They specify the connection line between the wildfire phenomenon and response on the one hand and the training curriculum on the other. To operationalise training assumptions, relevant participants and equipment were described.

Chapter 3 is dedicated to training guidelines for preparation and pre-planning activities in wildfire response. The SILVANUS approach to systematic methodology for the preparation and pre-planning activities for wildfire response was presented, which reflects the ‘step-by-step’ formula to compile information necessary to devise a training curriculum in a replicable and rational way. In addition, an analysis was carried out of data and information as crucial resources in pre-planning and preparation activities for wildfire response. Focusing on training objectives, forms and methods and on materials has made it possible to clarify specific methodological issues that are ‘ready-to-use’ in the preparation and pre-planning of wildfire response in the form of training.

Chapter 4 is strongly technology-related. Results of an in-depth analysis of the SILVANUS technosphere in support of preparation and pre-planning activities in wildfire response were compiled and discussed. The focus was on detection technologies, computational tools, end-technology tools, functionalities of the decision support system and societal involvement tools. Every solution was described to present its general idea, an approach to how it works, relationships to particular phases of wildfire management, specific relationship with preparation and pre-planning activities for wildfire response, as well as training guidelines for simultaneous use of the technology and maximising the educational effect.

Chapter 5 presented information collected into a form that is practical for training organisers and technology providers. This allowed the establishing of training protocols. To reflect the ‘step-by-step’ formula, particular phases of wildfire response were taken into account, and namely: early detection and communication of a hazard, immediate dispatch of wildfire responders, effective deployment of the resources to the wildfire scene, comprehensive reconnaissance of a hazard situation, firefighting tactics, and cooperation between firefighting actors. In case of every response phase, its general approach, operational needs, technology functionalities desired, SILVANUS technologies recommended (with indicating purposes of their deployment into training processes), recommendation of connecting particular technologies to particulate technology functionalities, and exemplary training protocol were outlined. This provides practical information on how to organise effective training benefitting from new technologies.

Research procedure required an in-depth analysis of literature (data bases, legal acts, guidelines, procedures, case studies, and descriptions of good practices), three survey sessions involving SILVANUS partners, three international scientific seminars on preparation and pre-planning activities in wildfire response (on ‘Objectives and Scope of the Training’, 29 June 2022; ‘Training Forms and Methods’, 29 September 2022, and ‘Training Materials’, 15 December 2022), and a comprehensive technology review. Individual results were discussed during the IV International Scientific Seminar on Preparation and Pre-Planning Activities for Wildfire Response on ‘Training guidelines on data and information flows between wildfire responders' and 'Guidelines on effective curricula for training related to preparation and pre-planning activities for wildfire response' (30 March 2023). Technology analyses were implemented both theoretically and practically (during SILVANUS pilots organised in 2023). These research methods allowed to effectively collect information, analyse it, shape new knowledge, discuss research results and transform them into the form of this research monograph.

Chapter 1. Wildfire – the phenomenon and the response

1.1. Definition and causes of a wildfire

A wildfire, also known as a forest fire, a bushfire, a wildland fire, or a vegetation fire, is the uncontrolled and unpredictable burning or combustion of plants in a natural environment, such as the woods, grassland, scrub or tundra, that consumes natural fuels and spreads under the influence of environmental conditions (e.g. wind, topography) (EUFOFINET, 2012; CIFFC Glossary, 2022).

Wildfires are a global phenomenon with serious consequences for the natural environment and humans. A fire in the woods can have both positive and negative impacts on the development of fauna and flora. Fires in the natural environment have always occurred, and some ecosystems became adapted to its occurrence or even dependent on periodic fires. In fire-adapted areas, fire promotes plant and wildlife diversity and burns accumulated live and dead plant material (leaves, branches and trees). It is a key element in the functioning cycle of ecosystems. In many cases, it is an essential element shaping the ecosystem, its health, and sustainability (Cumming, 1964; Wiłkomirski, Gutry, 2010; Wright, Heinselman, 2014; Neary, 2020). A fire can be a landscape shaping tool through preventive measures aimed at biomass reduction. It can be used for fire suppression (Cumming, 1964; Fernandes, Botelho, 2003; Rego et al., 2010).

The situation is different in ecosystems where natural fires occur rarely or not at all. In such cases environmental damage becomes very significant– the biodiversity decreases, forest ecosystems, flora and fauna perish, and the soil becomes prone to erosion. The effects of fires also affect people. A fire carried by the wind can quickly approach inhabited areas, causing panic and chaos. Communities living near forested areas are at risk of death if evacuation is not carried out. Infrastructure can be destroyed. Moreover, wildfires have long-lasting consequences. They lead to the loss of biological diversity on the one hand and to environmental degradation on the other. Areas with diverse species are usually replaced by invasive ones (Wiłkomirski, Gutry, 2010). Soil erosion, changes in species composition, and habitat loss are common consequences of fires. The emission of combustion products: smoke and toxic substances contained in it, poses a threat to the health of humans and animals. The emission of gases and toxic substances affects air quality, having negative effects on public health. What is more, forest fires disrupt global biogeochemical cycles, especially the global carbon cycle (Yang et al., 2015; Palviainen et al.,2020; Agbeshie et al., 2022; Gromek 2024).

Wildfires do not occur spontaneously. They can be caused by various factors, both natural and anthropogenic. Their vast majority is the result of human activity. But they might be caused also by natural phenomena such as lightning strikes (Taylor, 1973; Davidenko, 2004). Natural sources of fires include lightning strikes, indirectly caused by heat waves that make the forest highly flammable. Anthropogenic factors include, among others, careless use of fire (e.g., spills from non-forest areas), criminal/terrorist activity, and dangerous and negligent behaviour of people in the woods, such as campfires. According to the harmonised classification scheme of fire causes in the European Forest Fire Information System (EFFIS), there are 6 categories and 30 classes of fire causes. EFFIS was developed by a group of experts from the EU, the Middle East, and North Africa and is one of the main components of crisis management services in the EU Copernicus programme. The classification was made to accurately record information about causes. Table 1 shows the division into individual categories, groups and classes.

Table 1. Classification of wildfire causes

CATEGORY	GROUP	CLASS
100 UNKNOWN	100 Unknown	100 Unknown
200 NATURAL	200 Natural	201 Lightning
		202 Volcanism
		203 Gas emission
300 ACCIDENT	300 Accident	301 Electrical power
		302 Railroads (Railways)
		303 Vehicles
		304 Works
		305 Weapons (firearms, explosives, etc.)

CATEGORY	GROUP	CLASS
		306 Self-ignition (auto-combustion)
		307 Other type of accident
400 NEGLIGENCE	410 Use of fire	411 Vegetation management
		412 Agricultural burnings
		413 Waste management
		414 Recreation
		415 Other negligent use of fire
	420 Use of glowing objects	421 Fireworks, firecrackers and distress flares
		422 Cigarettes
		423 Hot ashes
		424 Other use of glowing object
500 DELIBERATE	510 Responsible (arson)	511 Interest (profit)
		512 Conflict (revenge)
		513 Vandalism
		514 Excitement (incendiary)
		515 Crime concealment
		516 Extremist
		517 Motive unknown
	520 Irresponsible	521 Mental illness
		522 Children
600 REKINDLE	600 Rekindle	600 Rekindle

Source: (Camia et al., 2014)

As regards EFFIS assumptions, the causes of individual fires are intended to be linked with satellite spectro-photometric data in a relational database. Currently, the Copernicus system provides several useful web-based tools on a free access basis, such as:

a) a browser for the current fire hazard situation along with a forecast for up to 6 days (data is daily updated based on satellite remote sensing, with hotspots and fire perimeters overlaid on maps, but there is no information about fire causes);
b) a statistical portal containing historical data on burned area and the number of fires, as well as other statistics;

c) the Firenews portal, which overlays information about current fires on a map;
d) long-term fire weather forecast;
e) a browser for fire hazard maps.

The above tools are publicly available in the Internet (EFFIS, 2024).

Natural sources of wildfires can occur individually or in combination, depending on the climatic and geographical conditions in a given area. There are three classes of natural causes:

a) lightning strikes,
b) volcanoes,
c) gas emissions.

Lightning strikes are one of the most common natural triggers of wildfires (Veraverbeke et al., 2017; Janssen et al., 2023). The onset of a wildfire often begins with a lightning strike to a single tree or the ground in the woods. A lightning strike hitting a tree can either ignite it immediately or transfer electrical energy to the roots, which can ignite dead organic matter or decay material in the soil. Additionally, it has been shown that lightning strikes can influence the species composition of trees. If a tree does not burn completely, it may eventually die. It is estimated that lightning strikes cause the death of about half of all affected trees with a diameter over 60 cm. Given the nature of this phenomenon, tall trees are usually targeted. Studies conducted in tropical forests have shown that tree mortality from lightning strikes depends on tree species (Richards et al., 2022). A typical lightning strike converts a large amount of electrical energy into thermal, sound and mechanical energy. The average energy of a lightning bolt is estimated to be around 1 gigajoule (GJ), but this is an approximate value that can vary significantly depending on the specific case as the bolt power depends on many factors. It is estimated that the average current of a lightning strike is 36 kiloamperes (kA) (Dul'zon, 1996). At the moment of a lightning strike, electrical energy released in the form of electrical discharge generates huge amounts of heat in the vicinity of the impact point. The temperature of the electric arc reaches 30,000 K. This intense heat energy can cause the surrounding air to heat up to temperatures of several thousand K degrees, which is sufficient to ignite organic materials such as a wood, vegetation or dry leaves. The heat energy causes a rapid increase in air pressure around the impact point, generating the characteristic thunder sound known from storms. This expansion violently raises the pressure around the impact point, generating a shockwave that propagates spherically. Lightning strikes, in addition to heat, light and sound waves, emit a wide range of electromagnetic waves, which may be heard on the radio as disruptions in the form of single clicks. The emitted frequency is generated over a very broad range of radio frequencies. By using two receivers spaced apart and digital signal processing, it is possible to accurately locate lightning strike locations, which can contribute to locating the source of a fire. In Europe, there is a special lightning detection network called the European Cooperation for Lightning Detection (EUCLID). There are also devices that record changes in the electromagnetic field caused by lightning. These detectors are used in various locations such as buildings, airports or industrial facilities to warn of approaching storms. Also visual systems are available for the monitoring of lightning. Detection systems may be equipped with optical sensors that record lightning flashes and allow the determination of the location of the strike based on the recorded image. Meteorological observation satellites equipped with sensors are used in satellite technology to detect lightning flashes from orbit. These satellites can track lightning activity over large areas, which is useful for monitoring storms on a global scale.

Wildfires caused by volcanic activity are statistically rare phenomena because two conditions need to be met. The woods must be located in the vicinity of a volcano, and the volcano must be active. In the majority of cases, a fire occurs when lava reaches areas covered with vegetation or dead organic matter. The temperature of lava reaches 1500 K and its solidification occurs at temperatures of 800–1000 K, which means that the solidification temperature itself is above the ignition temperature of organic materials. Additionally, lava has a high thermal inertia, and its cooling takes place through the release of energy to the surroundings through conduction, convection and radiation. Fires occur cyclically at active volcanoes. An example is the Kilauea volcano in Hawaii. The last eruption occurred in 2020, and the formation of the volcano is estimated to have occurred 300–600 thousand years ago. Since its formation, the volcano has been continuously active, rising to a height of over 1200 m above the sea level and covering old lava with new layers. Between the layers of lava there is charcoal, which indicates the age-old struggle of vegetation with the volcano. The ignition phenomenon from volcanic eruptions can have three direct causes (Quah et al., 2023), which are listed in Table 2.

Table 2. Direct causes of ignition phenomenon from volcanic eruptions

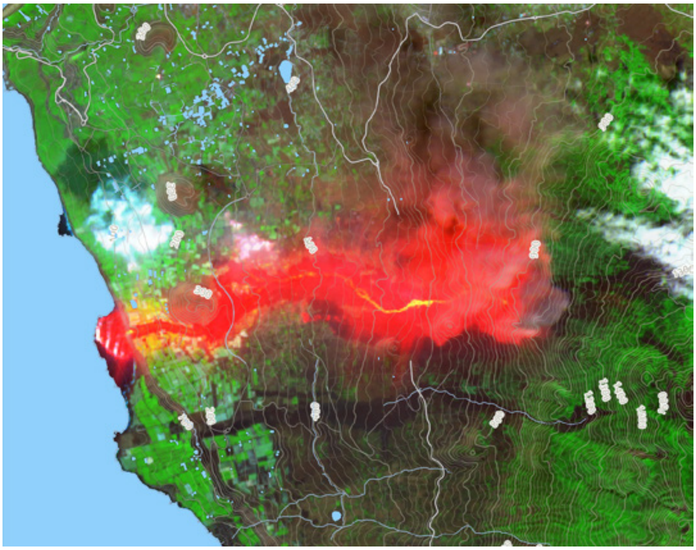
Causes of volcanic eruption phenomenon	Type of destruction
Liquid lava	Direct ignition of biomass by radiation or conduction
Volcanic ballistic projectiles (VBP)	The heated volcanic debris ejected from the volcano interior can be ejected several kilometres away from the crater.
Pyroclastic density currents (PDCs)	The propelled and heated mixture of gases and ashes burns any organic matter encountered along its path.

Source: own work based on (Quah, 2023)

Volcanic eruptions are often accompanied by lava flowing down the slopes of the volcano. Passive forms of volcanic activity in the form of long-lasting magma lakes are less common. Usually, the magma located at the summit escapes through dykes, fissures and cracks in the crater rim. Quite frequently, magma finds its way out at the base of the volcano. The speed of lava movement depends on its viscosity and the inclination of the slope, usually at a few kilometres per hour (km/h). Upon contact with organic matter, it ignites because its temperature exceeds 800°C in the liquid phase. Fissure eruptions usually have a cyclical nature. An example of this is the Miyakejima volcano on one of the islands of Japan. The intervals of its activity are estimated at 76–78 years over the past 1100 years (Cappello et al., 2015).

Figure 1 depicts the activity of the Cumbre volcano on the island of La Palma in the Canary Islands archipelago. The presented spectrophotometric images show a view of the active volcano in the short-wave infrared SWIR band, showing the emerging lava flow. The subsequent two images illustrate spectrophotometric images of the same area taken before the eruption and during the eruption. The images depict the Normalized Difference Vegetation Index (NDVI), a valuable tool for non-invasive vegetation assessment, derived from the difference between red and near-infrared radiation reflection. Based on the differences, complete destruction of organic matter around the lava flows can be observed.

Volcanic ballistic projectiles (VBP) are a phenomenon of volcanic mineral ejection, which is extremely violent by nature. A well-documented case was the eruption of the Pacaya volcano on May 27, 2010, in Guatemala (Wardman et al., 2012). Shortly after a 45-minute eruption, heavy rainfall was recorded. The traces of VBP bombardment were well preserved. Half-meter ballistic fragments were found 1 km from the crater. There were also fatalities among people. Three villages located within 3.5 km from the crater were affected by the consequences of VBP. The falling volcanic debris had a temperature of 600-800°C and served as the initiating source of fire upon impact with organic matter.



The spectral range of SWIR (Short-Wave Infrared) Thermal activity was captured on the satellite image.

NDVI Index – before the eruption on September 10, 2021.

NDVI Index – during the eruption, image from September 30, 2021.

Figure 1. Satellite images of eruption of the Cumbre volcano on the island of La Palma (Canary Islands)

Source: own study based on satellite data from the EFFIS portal (EFFIS, 2024)

Pyroclastic density currents (PDCs) consist of a mixture of hot gases, ash and larger particles including volcanic debris. The flow of such a mixture occurs gravitationally. The source of PDCs is typically the crater crown. During eruptions, the heated mixture, similar to an avalanche, flows down the crater slopes, accelerating under gravity in some cases up to several tens of meters per second (Lerner et al., 2022). The PDC mixture can stratify into fractions and move at different speeds. The dynamics of the phenomenon are so significant that there is practically no escape for humans or animals, especially in the event of the lighter fraction of PDCs separating from the main stream. The temperature of PDCs reaches 600°C, and its range of influence can span several kilometres. This is a highly dangerous phenomenon that claims many lives. Vegetation in the path of the PDC avalanche immediately ignites. People and animals suffer from burns or death depending on the path taken and the intensity of the PDCs. Following eruptions of the Merapi volcano in Java in 1994 and 2010, only one-third of hospitalised burn victims survived (Baxter et al., 2017). Rapid PDCs can also kinetically move across flat surfaces, leaving larger fractions in terrain depressions.

In the zone of continuous permafrost degradation, a rapid release of methane takes place. This phenomenon is observed in the northern hemisphere in Eurasia, as well as in Canada, Alaska, the Arctic, and along the seabed off the coast of Western Spitsbergen (Westbrook et al., 2009). Long-term measurements of methane concentration are being carried out in many locations using electronic detectors. Concurrently with local measurements, satellite observations are conducted, including those using Sentinel-2 L1C. Analyses indicate that the thickness of continuous permafrost in many wetland areas is gradually decreasing. The phenomenon is most intense at the boundary of continuous permafrost. Methane hydrate stored in the continuous permafrost beneath wetland areas is gradually released into the atmosphere in the form of methane (Shan et al., 2020). Correlations between the frequency of wildfires and the activity of methane release at the borders of continuous permafrost have been observed (Shan et al., 2022). This phenomenon is concerning because it is estimated that the global amount of carbon stored in methane hydrate is twice the amount of global coal reserves in solid form. It has been shown that 1 m^3 of relic hydrate contains 160 m^3 of methane. The presence of *Relic Hydrate* has been confirmed, among other things, by studies of ice core samples in north-western Siberia (Yakushev et.al., 2018). It is worth noting that according to the harmonised scheme of classification of fire causes adopted by the EU for the European fire database EFFIS, gas emission is classified as a cause of a fire, although it is not a direct initiating factor because the presence of methane alone will not cause a fire without an external initiator. Therefore, for this case, gas emission is not a direct cause of wildfire occurrence. However, there are places on Earth where natural gas is emitted. *The Chimera Fire* is an example. This was located in Turkey in the province of Antalya, where many places of perpetual natural gas burning are found in a small area.

Anthropogenic causes of fires account for approximately 90% (Wiłkomirski, Gutry, 2010; Kolanek et al., 2021) of all fires. This is an estimated value because the exact causes of all fires worldwide are not known. However, there are statistical data from individual regions where such statistics are kept. Depending on the region, these values may vary depending on factors such as proximity and degree of urbanization of the area, density and type of roads, population density, size of nearby urban areas, presence of railway lines, etc. The issue of anthropogenic causes of fires is highly relevant and has been addressed by many researchers. Often the impact of a specific factor on two different areas has yielded conflicting results, such as road density (Kolanek et al., 2021).

Three categories can be distinguished: accident, arson and negligence. Possible causes of accidents involving human factors are presented below (Table 3).

Table 3. Anthropogenic causes of accidental fires

CLASS	Possible causes
301 Electric power	a) sparking from damaged power lines b) tearing of power lines due to icing c) overheating of wires due to current overload d) improper maintenance work e) falling branches or trees on power lines f) damage to insulation
302 Railroads (Railways)	a) tearing of railway traction b) discarded cigarette butts thrown out of windows c) sparks from the braking system d) sparks from wheels e) worn-out axles f) railway accidents g) damaged locomotive
303 Vehicles	a) cigarette butts discarded or left along the vehicle route b) picnic fires c) sparks from the braking system d) worn-out rotating components e) catalytic converters f) goods lost during transport g) short circuits in electrical installations h) sparks from the exhaust system i) traffic accidents j) leaks of flammable substances
304 Works	a) explosions due to improper processing of flammable materials b) damaged agricultural or industrial machinery c) sparks from chimneys d) woodworking activities
305 Weapons (firearms, explosives, etc.)	a) use of flares or illuminating torches b) misfires c) use of firearms in field or forest conditions d) rocket exhaust gases e) military training exercise

CLASS	Possible causes
306 Self-ignition (auto-combustion)	a) chemical reactions b) concentration of sunlight
307 Other accident	All accidents involving humans not covered by classes 301 to 306.

Source: own study based on (Camia et al., 2014)

In the negligence category, there are two groups of wildfire triggers: the use of a fire and glowing objects (Table 4).

Table 4. Anthropogenic causes of fires due to negligence

CLASS	Possible causes
411 Vegetation management	All types of burning except burning for agricultural purposes
412 Agricultural burnings	a) burning meadows, pastures, fallows and reed beds b) burning from agricultural land
413 Waste management	c) burning waste at landfills d) incineration of garbage
414 Recreation	Fires caused by bonfires, grills and recreational activities
415 Other negligent use of fire	Other forms not specified previously
421 Fireworks, firecrackers and distress flares	The use of all types of pyrotechnic devices
422 Cigarettes	Fires caused by burning cigarette butts, matches or pipe ashes
423 Hot ashes	Ashes from grills and other fireplaces
424 Other use of glowing object	Other forms not specified previously

Source: own study based on (Camia et al., 2014)

In the category of arson, there are two groups: arson caused by adults who are responsible for their actions and arson caused by minors or mentally incapacitated individuals (Table 5).

Table 5. Anthropogenic causes of arson fires

CLASS	Possible causes
511 Interest (profit)	Motivation for arson being material gain or other benefits
512 Conflict (revenge)	Motivation for arson being conflict of interests or retaliatory action
513 Vandalism	Malicious intent without ulterior motive
514 Excitement (incendiary)	Desire to draw attention, for example, in a situation of danger or for other mundane reasons
515 Crime concealment	Actions to cover up evidence of a crime
516 Extremist	Sabotage actions with extremist motives, undertaken to cause material damage
517 Motive unknown	Reason unspecified above
521 Mental illness	Cause stemming from mental illness
522 Children	Fires caused by minors

Source: own study based on (Camia et al., 2014)

Category 600: Re-ignition refers to all cases where the source of the fire is an unextinguished primary fire. Apart from the mentioned natural and anthropogenic causes, there are also unclassified reasons for forest fires (Category 100). This applies to cases where there is no clear answer as to what the actual initiator of a wildfire was.

1.2. Conditions for the origin and development of a wildfire

Three key elements are required for ignition and spread of a fire: fuel, heat, and (in the most cases) oxygen. These elements are commonly referred to as “the fire triangle” (see Figure 2). Fire is the result of a chemical reaction called combustion, which predominantly occurs between oxygen in the air and fuel heated to its ignition temperature (the lowest temperature at which ignition occurs). Fuel can consist of any combustible material, including trees, grass and shrubs. The structure, quantity, availability and moisture content of each flammable material determine the spread of the fire. Heat provides the energy needed to vaporise flammable gases, which, in combination with oxygen, enable the combustion process, raising the fuel to its ignition temperature by causing vaporisation and mixing with oxygen. A fire can only occur when all three components react together. Therefore, to extinguish a fire, at least one of the components of "the fire triangle" needs to be eliminated (Pyne, 1996; Alexander, 2001; Güngöroglu, 2019).

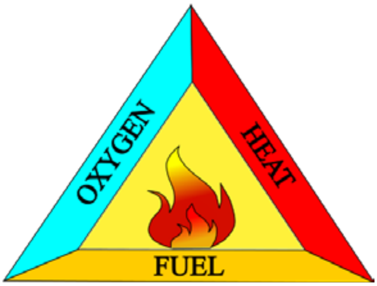


Figure 2. Fire triangle

Source: own work

Wildfires behave differently depending on the terrain where they occur and factors associated with fuel materials and meteorological conditions. Understanding the differences in fire behaviour is important for determining tactics and strategies for fire suppression in the woods.

The phenomenon of fire is determined by the interaction of fuels, weather and topography (see Figure 3). These factors are collectively referred to as "the wildfire behaviour triangle".

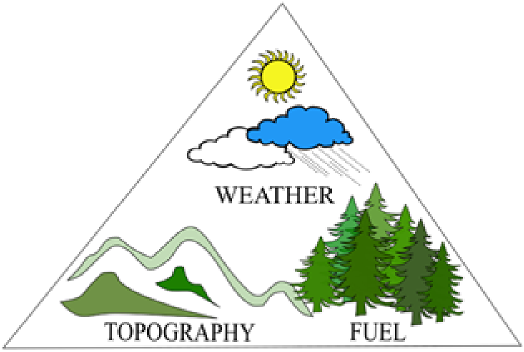


Figure 3. Wildfire behaviour triangle

Source: own work

In addition, the triangle may be time-determined and supplemented by vegetation, climate and ignitions that commonly define a fire regime (See Figure 4).

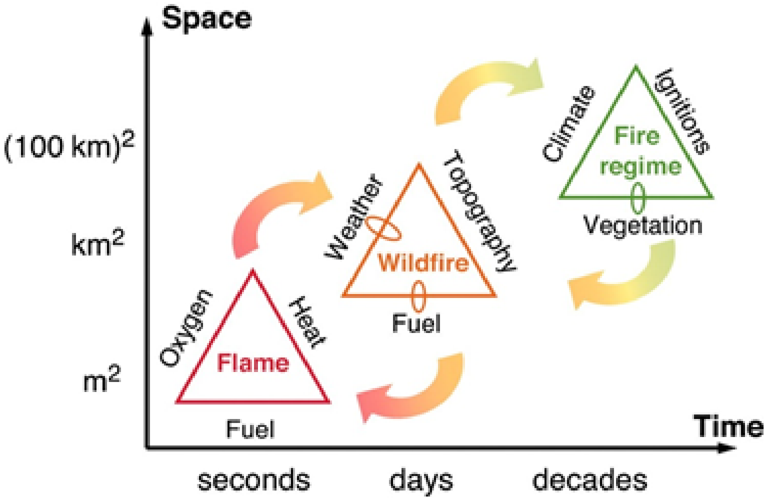


Figure 4. Wildfire behaviour triangle

Source: (The Climate Advisor, 2022)

The fire spread occurs under the condition of the exothermic reaction of combustion. In such cases, the heat energy released during the combustion of flammable material must be greater than losses. The heat generated during the reaction heats up the adjacent fuel material, causing its thermal decomposition. The resulting flammable volatile phase ignites, causing the fire to develop. The fire spreads wherever there is flammable material.

Indicators of fire spread include the rate of movement of the fire line as well as the perimeter and area of the fire. Components of the shape of a fire include the front (head), flanks (wings, flanks) and rear (see Figure 5) (Eftychidis, 2013).

The fastest-moving, hottest and most dangerous part of a wildfire is called the head (front). The fire front is the area where the fire develops and spreads most actively. It is the part of the fire that is most critical for firefighters and firefighting services because their efforts focus on controlling and extinguishing it. The fire front is characterised by intense fire development, high temperatures and rapid-fire progression. Conditions at the front can be very dangerous for people and difficult to predict due to the dynamic nature of the fire.

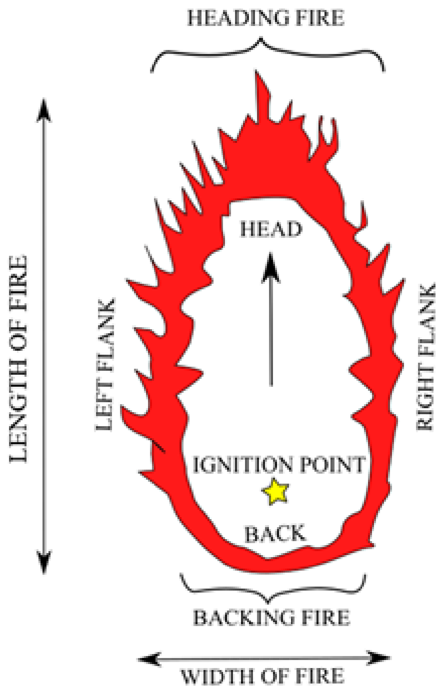


Figure 5. Components of a wildfire

Source: own work

The rear (back) is typically opposite to the head and is the closest to the ignition source. The rear of the fire often exhibits lower fire intensity and temperature compared to the head. The rear part of the fire usually burns more slowly than the other components. Flames at the tail are typically directed towards already burned fuel, and the fire spreads into the vegetation against systems that favour the head fire. The tail fire is potentially the slowest-moving part of the fire with the shortest flame length. Although the rear of the fire may seem less significant, it requires attention because smouldering sources of fire may be present there, posing a threat to firefighting lines and potentially contributing to fire re-ignition.

The flanks of a wildfire are areas on the sides of the head. The fire flanks burn outward, towards unburned vegetation. These result in the flanks being less aligned than the head, which typically reduces their intensity and rate of spread. Flank fire spreads at right angles or diagonally to the wind direction. Generally, it moves slower, has lower intensity, and is easier to control than the head fire. Differences in fire activity may occur on each flank due to changes in fuel type or topography. This can lead to different fire behaviour on each flank. Flank fire is less active compared to the head, but it can still be a place of intense fire development, especially when the fire moves along various terrain or topographic lines (Eftychidis, 2019; Alexander, 2001).

The remaining parts of a wildfire include: fingers, pocket, perimeter, islands (see figure 6) (Rothermel, 1972; Alexander, 2001).

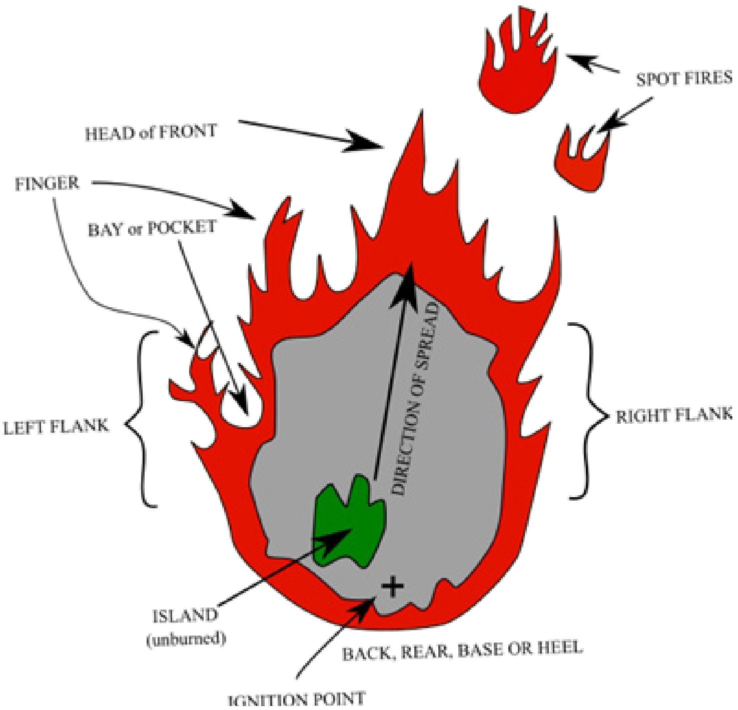


Figure 6. Parts of a wildfire

Source: own work

Islands are areas that have not been completely burned within the fire perimeter. These can be single trees or clusters of vegetation surrounded by already burned areas. Islands pose a potential threat as they may contain smouldering organic materials that could reignite, especially with changes in wind direction or other atmospheric factors.

“Fingers” are narrow, elongated areas of the fire characterised by the fire edge moving along terrain or topographic features. They may be caused by changes in wind direction, terrain shape, or the presence of fuels that facilitate rapid fire spread along lines. Fingers can be challenging to control due to their dynamic nature and the potential for rapid fire spread to new areas, requiring constant attention and response from firefighters.

Pockets are areas within the main fire front that remain unnoticed or unseen from the outside. They could comprise depressions in the terrain, dense vegetation clusters, or other locations where the fire can hide and develop without clear external signs. Pockets can be difficult to detect and control, posing a potential hazard to firefighters who must be vigilant for hidden fires and take appropriate precautions during firefighting operations.

Spot fires are single or clustered new fire ignitions that appear outside the main fire area. They may be caused by wind-blown sparks or embers from the main fire front. Spot fires pose an additional hazard to firefighters as they can quickly spread and lead to the emergence of new fire areas that require immediate attention and response (Rothermel, 1972; Alexander, 2001).
Understanding the components of a wildfire is crucial for a comprehensive assessment of the situation, effective planning, and firefighting actions.

The course of a wildfire can be divided into four phases. Phase I means ignition of the fire. The duration of the first phase of a fire is irregular and lasts from 5 to several dozen minutes. It depends on the physical properties of the combustible material, such as thermal conductivity, specific heat, and bulk density. In addition to physical properties, the duration of Phase I is influenced by the amount of thermal energy supplied by the energy stimulus absorbed by the combustible material. Phase II concerns intense burning /ignition/. The second phase covers the period of fully developed fire and is often referred to as the ignition phase. It is characterised by intense burning. The feature of this phase is the movement of the fire front, constant growth of the fire area, and shaping of external conditions by the fire, closely related to the combustion process. The development of the second phase depends on the type and quantity of combustible material and convective removal of heat and mass from the fire environment to the unburned space. Phase III is smouldering. It begins when the fire starts to die down, resulting in a decrease in temperature and the amount of emitted heat. The characteristic feature of this phase is smouldering and long-lasting glowing.

In a forest environment, where there is practically an unlimited amount of combustible material, the occurrence of the third phase may occur after the fire front has passed, when external conditions change and hinder the development of the fire (rainfall), the fire reaches obstacles (rivers, marshes, roads, firebreaks, etc.), or when firefighting action is taken. Phase IV is called “Cooling”. The fourth phase is characterised by the cessation of smouldering, and the temperature of the fire approaches the ambient temperature (Karlsson and Quintiere, 2000; Szczygieł, 2024).

The phases of wildfire development can vary depending on the specifics of each fire, including the type of fuel, weather conditions, and terrain topography. The spread of a wildfire is influenced by many variables, such as meteorological and topographical conditions, fuel load (amount of flammable biomass), and other factors. The primary factors affecting fire spread include:

a) wind,
b) relative humidity of the air,
c) moisture content of the fuel,
d) type of fuel and its density (packing), structure, quantity,
e) terrain topography.

As regards meteorological conditions and weather, wind has the greatest impact on the spread of fire. It directly affects the speed and direction of fire spread. Depending on the strength and direction of the wind, the direction and speed of fire spread, the intensity of burning, the shape of the burned area, and the occurrence of spot fires may change. The significance of wind lies in changing the angle of flame inclination. Wind bends and tilts the flames around the fuel, causing it to dry and ignite faster (see Figure 7). Additionally, it supplies oxygen, leading to increased burning intensity. Wind carries ashes and other particles generated by the burning fuel, which can result in the ignition of new spot fires (Rothermel, 1972; Green et al., 1983; Wiler, Wcisło, 2013; Szajewska, 2014; Szczygieł, 2017).

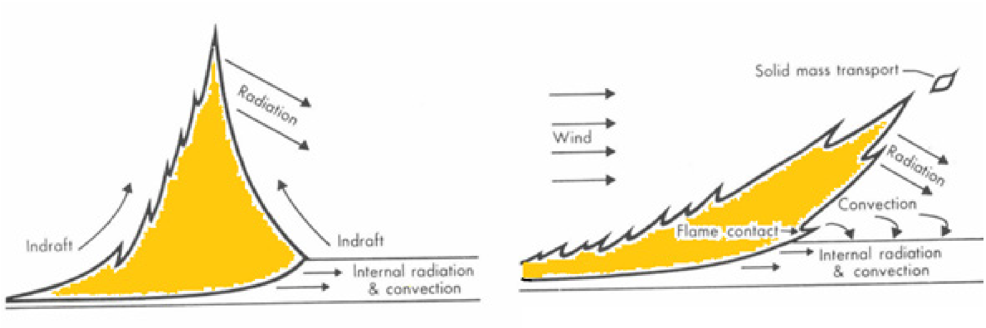


Figure 7. Influence of wind speed on flame tilt

Source: (Rothermel, 1972)

Fire primarily spreads in the direction of the wind, assuming a shape corresponding to its strength (Figure 8). The greater the wind speed, the longer the horizontal axis of the ellipse, and the shorter the vertical axis (Szajewska 2014, Szczygieł 2017).

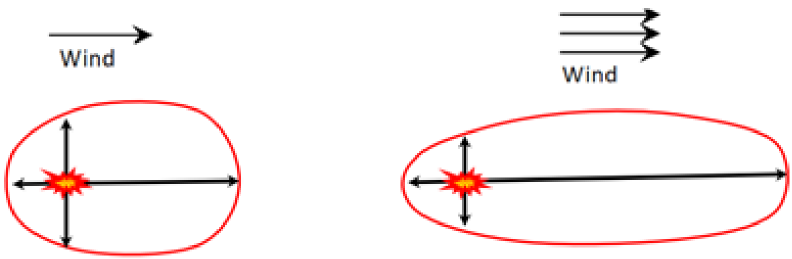


Figure 8. Influence of wind speed on fire shape

Source: own work

Variable wind strength and direction, as well as the distribution and properties of the fuel, can influence the shape of the fire. This can lead to deviations/disturbances from the classical, model shape, for example, the formation of islands (see Figure 9).

Figure 9. Remaining unburned fuel

Source: own work

Gusty winds with variable direction and speeds of 6–10 m/s are most dangerous for the development of fires. They lead to frequent changes in the direction of fire spread and generate convective currents of heated air, which promotes the spread of fire spots. With winds above 10 m/s, convective currents do not occur with such frequency, and the winds contribute to a relative stabilization of fire development and its direction (Szczygieł, 2024).

Among the other important meteorological factors, relative humidity, temperature and precipitation should be mentioned. They significantly affect the moisture content of the fuel material. The higher the moisture content, the slower the combustion process, as more heat is needed to evaporate the water. Relative humidity affects fires by either dampening or drying potential fuel. It is an important factor that can determine the development of a fire because the higher its value, the slower the spread of the fire. Relative humidity up to about 60% has no significant effect on the rate of fire spread. With relative humidity values above 70%, the spread of fire is clearly limited, which is particularly important in extinguishing ground cover fires (Moinuddin et al., 2021; Szczygieł, 2024).

As regards topography, the spread of wildfire depends on the terrain configuration. In flat or sloped terrain, fire can spread uphill or downhill, depending on the encountered elevation. Depending on the terrain configuration, three forms of fire development may be distinguished (see figure 10):

a) horizontal,
b) upslope,
c) downslope.

Whether the fire spreads up or down the slope affects the speed at which the fire line moves (Szajewska, 2014).

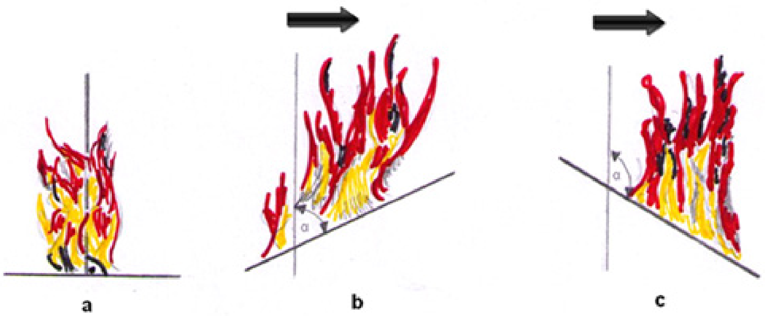


Figure 10. Forms of fire development depending on the terrain slope a) horizontal fire α=90° b) upslope fire α<90° c) downslope fire α>90°

Source: own work

A fire moving up the slope generates more heat through convection and radiation, which heats up the combustible materials encountered along the fire path, as compared to a situation on flat terrain (Figure 11).

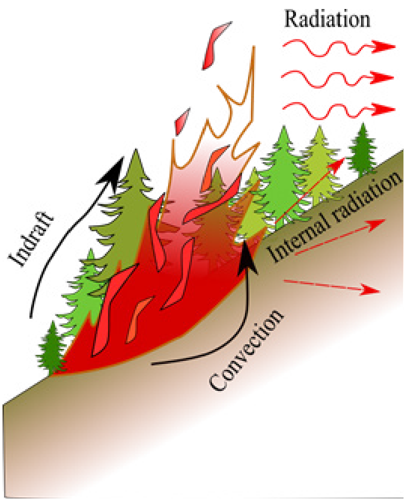


Figure 11. Behaviour of fires on a slope

Source: own work

The steeper the slope, the more intensified this effect becomes. Conversely, when burning downhill, the situation is different. The greater the speed of fire spread, the steeper the slope of the burning surface. The development of the fire uphill is faster because the inclination angle of the flames in relation to the unburned material is smaller (Figure 12). The downhill spread usually occurs more slowly. A dangerous phenomenon in this case can be the falling of burning materials down the slope, creating new fire spots. Generally, it can be assumed that for every 10° increase in slope, the speed of fire spread doubles. For every 10° decrease in slope, the speed of fire spread decreases by half (Szczygieł, 2024).

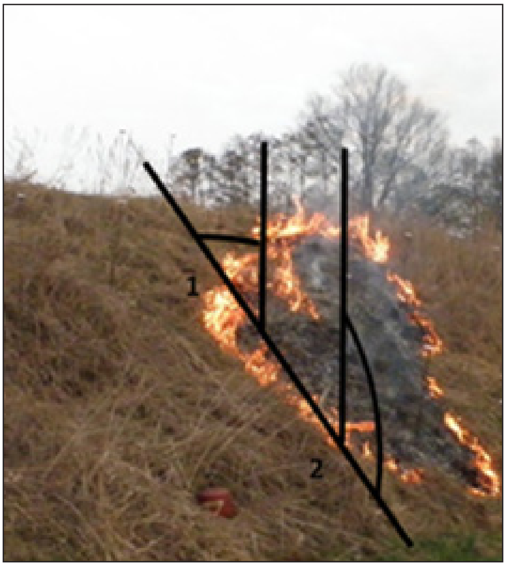


Figure 12. Upward fire: 1 – acute angle, 2 – obtuse angle

Source: own work

The shape of the slope can also affect the behaviour of fires. Straight slopes are likely to be characterised by a more uniform and predictable rate of fire spread. Concave slopes have an increased angle of inclination closer to the summit, which can cause a significant increase in fire intensity as it moves up the slope. A fire moving down a concave slope will gradually increase its intensity as the angle of inclination decreases closer to the bottom, where more heat can be transferred to unburned fuel. Convex slopes have a steeper angle at the base compared to the top, so the fire will be more intense at the base of the slope. As the fire moves up the slope, the angle of inclination decreases, and the amount of heat transferred to unburned fuel decreases (PWF, 2024).

The next factor that determines conditions for the origin and development of a wildfire is fuel. Fuel may comprise any material that can sustain combustion in a fire environment (EUFOFINET, 2012; CIFFC Glossary, 2022). Fuel material is the most significant factor determining the possibility of fire ignition and spread. It is a key element of the fire triangle. Their type, arrangement, moisture content, thickness and composition significantly influence fire development. Forest fuels are divided into live and dead fuels and into various size classes, such as fine fuels like leaves and twigs, and coarse fuels like logs. Because fine fuels have a large surface-to-volume ratio, they ignite easily and play an important role in increasing the rate of fire spread (Rothermel, 1972; Fujioka et al., 2009; Nolan et al., 2022).

Furthermore, the following flammable materials can be distinguished in forest ecosystems:

a) subsurface: organic parts beneath the litter layer, such as underground roots, peat;
b) surface: low vegetation, including leaves, grass, small shrubs, and large fallen logs;
c) canopy: trunks, branches, leaves of large living trees, standing snags or dead trees, and moss on them (materials not in direct contact with the ground).

Flammable material can be distributed vertically or horizontally. The horizontal distribution of flammable materials affects the relative ease of fire spread in a given area. The horizontal distribution, quantity, and distance between flammable materials determine the linear rate of fire spread. The more spaced apart flammable materials are, the slower the fire will spread. Conversely, the vertical arrangement affects the relative ease of vertical fire spread from the subsurface zone to the canopy layer.

Another factor influencing the development of a fire is the amount of forest flammable materials. In current terminology, the amount of fuel is determined by a parameter known as the fuel load, which represents the quantity of flammable material in a given area. Fuel load is measured by the weight of flammable material per unit area, typically expressed in kilograms per square meter. The fuel load can also be categorized relative to its quantity, such as high fuel load or low fuel load.

The amount of fuel affects:

a) released heat [kJ],
b) heat release rate [kW],
c) heat release rate per unit area [kJ/m² min],
d) linear fire intensity [kW/m],
e) combustion temperature [°C],
f) duration of the fire [h].

The values of these parameters impact the type and extent of damage as well as the organisation of firefighting efforts (e.g., the quantity of firefighting resources needed to extinguish the fire).

A very important factor influencing the initiation and development of fires is the moisture content of the fuel. It depends on meteorological factors and the exposure of the material. It is assumed that fire-resistant biomass has a moisture content of 50% or more. These are mainly green trees, living branches, and live ground cover. On the other hand, fire-active biomass is characterised by high variability of moisture, depending on atmospheric conditions. Examples of such biomass include dead wood, litter, dried grass, live small branches and needles (Rothermel, 1972). Fuel moisture limits the spread of fire. When the moisture content is high, fires are difficult to ignite and burn weakly, if at all. With low moisture content in the fuel, fires easily ignite, and wind and other driving forces can cause rapid and intense fire spread (Rossa, 2017; Nolan et al., 2022).

1.3. Types of wildfires

There are three main types of wildfires:

a) a ground (subsurface) fire,
b) a litter fire,
c) a crown fire.

During a fire, all three types of fires often occur. The spread of fires varies depending on the type of fuel present, its vertical arrangement and moisture content, and weather conditions.

As regards subsurface/ground fires, these fires typically occur in peat bogs as well as in deep mires. Their characteristic feature is smouldering combustion, high temperatures (reaching up to 1000°C), and a slow spread rate, ranging from several to several dozen metres per day. Subsurface fires are long-lasting, sometimes extending over several months. Ground fires are fuelled by underground roots, organic matter on the forest floor, and other buried organic material. They are difficult to detect, and their presence can be determined by the emergence of smoke, sometimes flames, when more air enters the burning zone, which occurs in strong winds (Figure 13).

Figure 13. Subsurface fire

Source: own work

Thermal images can prove to be very helpful in determining their extent. The direction of their spread can be determined by trees toppled due to damage to the root system (they fall with their crowns towards the burned area). The damage caused by subsurface fires results in the complete destruction of forest stands growing in the area affected by the fire and leads to ecosystem destruction.

Surface fires are the most common type of wildfires. They occur on the floor of the woods, and as they spread, the litter layer, moss, undergrowth, shrubs, fallen branches, saplings, bark, and shallow roots are burned. The surface fires occur throughout the year. These fires spread rapidly, at speeds of up to several meters per minute. Much slower are litter cover fires, which spread at a maximum rate of several meters per minute. Flame combustion during forest floor fires occurs mainly at the perimeter, within a width of about 0.5–2 m (Figure 14). It is most intense at the front and least intense at the rear of the fire. The rate of spread of the fire sideways and behind the fire is several to several dozen times slower than the speed of the front. The temperature of the flames reaches up to 900°C.

Figure 14. Subsurface fire

Source: own work

Complete stand fires encompass the entire vertical cross-section of the woods. They stem from ground cover fires, which shape the conditions for their spread. Fires in the tree crowns spread faster than on the forest floor, so after traveling a certain distance without ground-level fuel, they become extinguished. This phenomenon can be successfully utilized during firefighting operations. Complete stand fires mainly occur in the woods with ground cover rich in combustible materials, with an undergrowth layer, or in young stands where tree branches are close to the floor. Their spread is more intense during the day, especially in the afternoon, than at night. Burning temperatures can reach up to 1200°C in pine forests. Heated air generates convective currents, altering atmospheric conditions, and due to pressure differences between the fire environment and adjacent areas, fire spread is rapidly accelerated. Flame heights under these conditions can reach 20–30 meters above tree tops. Ahead of the fire front, new fire points can be created due to fire spotting, initially in the ground cover and then in the tree crowns. As a result, the fire front is irregular, and its maximum spread rate can reach several kilometres per hour.

1.4. Process of wildfire response

The process of responding to wildfires refers to the sequence of actions and operations undertaken in response to the onset of fire threat to control, extinguish, and subsequently mitigate the damage. This process, in the longer term, aims to restore conditions resembling the original state. It is a systematic approach that involves multiple stages, such as fire detection, resource mobilisation, coordination of activities, firefighting, and population evacuation. It is a complex mechanism that requires adequate preparation, coordination, and collaboration among various institutions and units, such as fire brigades, forestry services, volunteer rescue teams, medical services, and civil defence services. Figure 15 illustrates the wildfire response process.

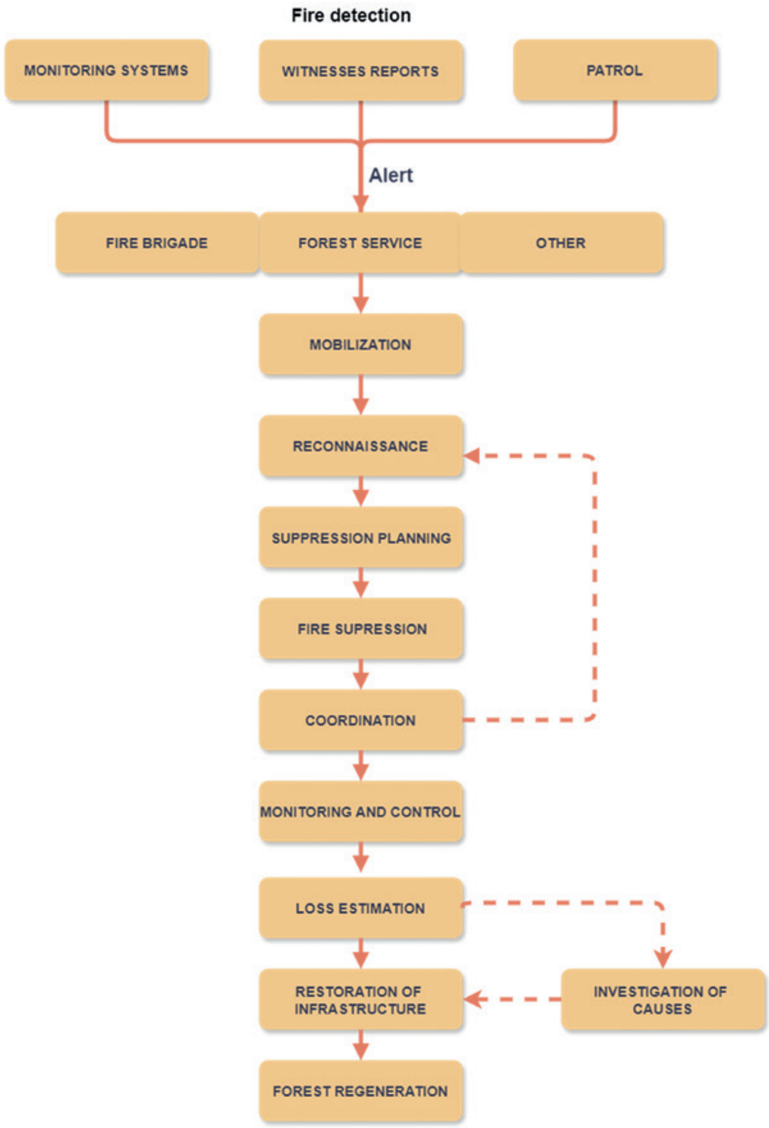


Figure 15. Wildfire response process

Source: own study

Early detection of wildfires is a crucial element of effective response. Modern technologies such as infrared radiation detectors, wireless sensor networks, and drones are utilised for detection (Wu et al., 2020). In the forested areas, fixed ground observation points, such as observation towers, are very helpful for fire detection. Observations from these towers can be conducted by an observer equipped with optical instruments and communication devices to connect with fire management centres. Currently, automatic fire detection systems are the most popular. These systems consist of cameras mounted on fire observation towers, transmitting images to fire management centres. These systems continuously monitor a designated area within a radius of up to 20 km. Using specially developed algorithms, the system can recognise and locate fire sources based on the recorded images. Cameras capture images in the visible and infrared ranges, and the supporting software is based on machine learning. Unmanned aerial systems are also used for image acquisition. Additionally, fire detection can be facilitated by local residents, tourists, forest ranger patrols, or national park personnel, as well as by the use of simple webcam systems. Despite existing imaging and satellite systems, satellites in low orbits are not used for rapid fire detection due to the long revisit time over a selected area. The long interval between revisits prevents immediate response (Szajewska, 2020). Conversely, rapid geostationary imaging systems lack sufficient spatial resolution for this purpose.

Once a fire is detected, it is necessary to promptly notify the relevant authorities, such as the fire brigade, forestry services, and other agencies responsible for firefighting. Three communication channels can be distinguished: radios – typically used by patrols or other forestry services, telephones, and electronic telecommunications networks. In the case of information obtained from witnesses, there may still be difficulties in establishing the exact location of the fire. Reports may occur individually or coincide with other reports. Despite providing different locations, many reports may concern the same fire. In areas monitored by fire observation towers, each reported alarm is verified by an observer who makes decisions regarding further actions. Detection of a fire by patrolling services, usually equipped with firefighting equipment, enables them to take preliminary actions aimed at limiting the spread of the fire.

Mobilisation of human and material resources needed to combat a fire is the next step. It comprises firefighting personnel, firefighting equipment, as well as transport means. This stage is crucial in combating wildfires because time plays a decisive role at this stage. The earlier the response reaches the fire site, the greater the likelihood of containing it from further development. Effective coordination of actions and rapid mobilization are necessary for an effective response to the fire threat and minimisation of its consequences. Firefighting personnel are a key element in combating wildfires. Depending on the scale of the fire, it may be necessary to involve various firefighting units, including the fire brigade, forestry services, or rescue units. Mobilising the appropriate firefighting personnel requires rapid coordination of actions and effective management of human resources. Firefighting equipment is an integral part of rescue operations. Depending on the type of fire and terrain conditions, it may be necessary to use various types of firefighting equipment, such as hoses, fire extinguishers, firefighting axes or generators. Mobilizing the appropriate firefighting equipment enables effective extinguishing of the fire and minimizes its spread. Transport means are essential for the rapid arrival of human and material resources at the fire site. These can include firefighting vehicles, fire trucks, firefighting helicopters, or firefighting aircraft. Mobilizing the appropriate transport means enables the rapid and effective movement of resources and firefighting personnel to the fire site, which is crucial for an effective response to the threat.

Upon arriving at the scene of the incident, the first step is to conduct a situation assessment. This assessment includes determining the size of the fire, the direction of fire spread (meteorological conditions), potential threats to people, and assessing available resources and terrain.

Based on the situation assessment, responsible authorities proceed to develop an action plan. Planning involves defining firefighting strategies, setting priorities, identifying threatened areas, and setting up defence lines. The planning process has a hierarchical structure, where the foremost priority is always human life, including the safety of rescuers and those providing assistance. Following that are cultural properties, social properties and infrastructure. Natural resources are at the bottom of the hierarchy. Planning decisions must be made thoughtfully, drawing on the knowledge of experienced firefighters supplemented by the insights of the community, which has at dispatch the most information about their area.

During planning, it is essential to consider the following:

a) there is no guarantee that every fire can be contained;
b) when fires are too extensive, driven by strong winds, or burning with high intensity (due to drought and accumulated fuel), there may be little that

can be done to stop the fire spread (in extreme conditions, airplanes and helicopters may prove ineffective);

c) the fire may be so intense that no personnel would be able to stop its spread;
d) firefighters and pilots should not be sent into situations where they cannot be safe, such as in poor visibility;
e) fighting every fire is neither possible nor desirable; some fires should be suppressed as quickly as possible, while others should be left without endangering firefighters' lives;
f) there should always be an alternate plan and contingency plans, especially regarding evacuation routes;
g) it is good practice to follow the PACE principle (P: Primary Plan, A: Alternate Plan, C: Contingency Plan, E: Emergency Plan.

The primary plan "P" is the preferred plan that yields the best results and is geared towards success of the operation. The alternate plan "A" is a riskier version of the primary plan. The outcome of the alternate plan may be less desirable than the primary plan. Plan "C" is entirely focused on the safety of firefighters. The contingency plan "C" is implemented when the fire or other conditions exceed the forecast, and it becomes necessary to withdraw to avoid injury or entrapment. The emergency plan "E" means that firefighter survival is the top priority. Firefighters should move to a safety zone. It is the duty of every firefighter to always have a designated safety zone in the right place. Ensuring that all personnel are aware of when and how to implement an emergency plan is crucial. Often the crew is separated when trapped by fire. The next good practice is to designate safety zones where one can take shelter. The diameter of the safety zone should be at least four times the flame height. Moreover, evacuation routes should be direct and obstacle-free. All decisions need to be based on the belief that the chosen solution will be successful.

Once resources and personnel are on site and the initial commands are given, active firefighting begins. Various extinguishing strategies are deployed, such as establishing fire lines, aerial water bombing from planes or helicopters, or using chemical agents. Every wildfire is unique in nature. Therefore, it is crucial to react appropriately and choose the suitable attack method based on the knowledge and information regarding fire behaviour, potential hazards, and environmental factors. Several tactics can be distinguished (The Scottish Government, 2013):

a) direct attack,
b) parallel attack,
c) indirect attack,
d) combined attack.

As regards direct attack, firefighters with equipment work directly on the fire perimeter. Water is sprayed directly onto the fire to reduce its intensity. This tactic is typically used for small, undeveloped fires that can be safely extinguished. The direct attack works best for fires burning light fuels or fuels with high moisture content, burning in light wind conditions. It is effective for low-intensity fires that allow firefighters to work close to the fire. The main advantage of the direct attack is firefighter safety. Firefighters can usually retreat back into the burned area, creating a safety zone. This is referred to as "keeping one foot in the black".

In accordance with parallel attack, this is done by setting up a fire line parallel to the fire edge but farther away than in a direct attack. This tactic can shorten the fire line by intersecting unburned fingers. In most cases, the fuel between the fire line and the fire edge is consumed due to setting up of the fire line.

When considering an indirect attack, firefighters with equipment work away from the fire perimeter to remove forest fuels from the path of the fire: building fuel breaks, controlled burning, setting up sprinklers, applying foam to separate the fire from areas where it is not desired.

As regards combined Tactics, it is deployed when responding to large fires. Combination of direct and indirect attack tactics is often necessary.

Effective coordination between various units and agencies is crucial for responding to fires efficiently. Communication and cooperation among the fire brigade, forestry services, medical units, and other involved institutions are essential for an effective response. Changes in the dynamics of the fire or weather conditions may require changing the adopted tactics or deploying additional actions. The coordination stage is linked to situational control and adjustments in firefighting planning.

Once the firefighting operations have been completed, it is essential to monitor the situation to ensure that the fire has been completely extinguished and to prevent any re-ignition of flames.

As regards damage assessment, after completion of the firefighting operation, damage assessment is carried out, which includes evaluating both material losses and the impact of the fire on the natural environment. Damage assessment is often linked to investigating the causes of the fire.

The final stage of the wildfire response process involves actions aimed at restoring the forest ecosystem. This process extends beyond the timeframe of the firefighting operation and can take many years.

If a threat to the population is identified, it is necessary to carry out evacuation and provide protection to residents and tourists, informing and evacuating people from endangered areas and providing shelter for those who need to leave their homes. These actions should be performed in a timely manner to ensure the safe evacuation of the entire endangered community.

The wildfire response process reflects specifics of safety and security management when considering wildfire conditions and circumstances. From the operational viewpoint of fire service, the processes may be operationalised, and it needs to refer to operational needs of firefighters who are the primary actors of wildfire response. Figure 16 presents the process in the perspective under consideration.

The first stage is early detection and communication of the hazard, which means the initiation of wildfire response. It is reasonable to detect hotspots as soon as possible, and to reduce risk of false positives. Once the hazard is identified, wildfire responders should be immediately dispatched to the action. Effective deployment of their resources to the wildfire scene is the third stage of the response. The next one is the comprehensive recognition of hazard situations. It relies on collecting information from multiple sources to determine a background for making decisions on wildfire response. It gives also input data to formulate firefighting tactics. The last stage means response activities in cooperation among multiple entities fighting the fire.

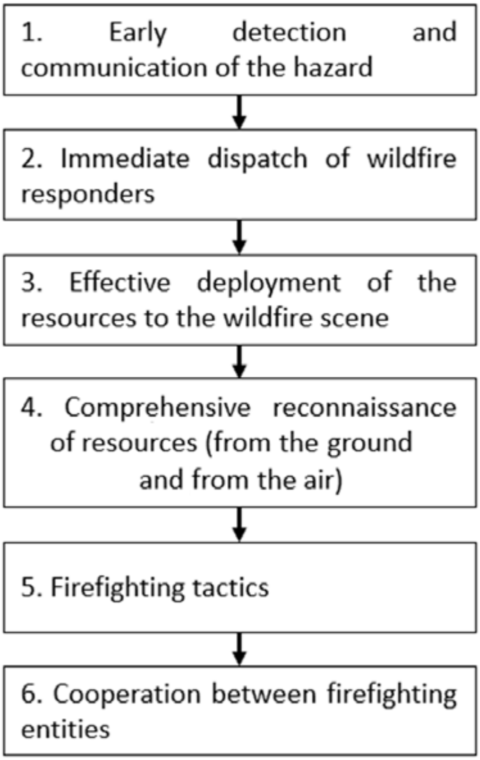


Figure 16. Wildfire response process – perspective of fire service

Source: own study

The perspective of the fire service on wildfire response process seems to be more operational for designing preparation and pre-planning activities for wildfire response. The fire service plays the primary role after the hazard occurs. Meeting the operational needs and expectations of firefighters is the key to increasing the response effectiveness. It is considered in the SILVANUS project and states reference for the systematic methodology for the preparation and pre-planning activities for wildfire response.

Chapter 2. Training related to preparation and pre-planning activities for wildfire response

2.1. Training needs stemming from wildfire specifics

Wildfires pose one of the most serious threats to the natural environment and human safety. They are often the result of a combination of natural factors such as drought, high temperatures, and strong winds, as well as anthropogenic factors like careless campfires, discarded cigarette butts, or deliberate arson. In today's world, due to climate change and increasing anthropogenic pressures, the threat of forest fires is becoming increasingly pressing. Therefore, there is a need for proper preparation and training of individuals responsible for managing and combating forest fires. Considering that training can also prevent fires, training needs have become very important due to the growing risk of these disasters and their potential impacts on the environment and human safety (Pimlot et al., 2014; Szajewska, 2018; CIFFC, 2022; Casartelli, Mysiak, 2023). Basing on this, the training needs are identified and listed in Table 6.

Table 6. Training needs

No.	Need	Description of need
1	Safety principles	All individuals present in the woods should be familiar with applicable safety rules.
2	Prevention	A key aspect of training is education regarding wildfire prevention. It includes informing local communities about risks associated with campfires, uncontrolled burning of grass, as well as promoting conscious use of the wooded areas.

No.	Need	Description of need
3	Monitoring and detection	People responsible for forest management and firefighting must be trained in monitoring the state of the woods and detecting potential fire threats. To achieve this, satellite technologies, smoke detectors, and early warning systems can be deployed.
4	Intervention	Training in wildfire intervention should include learning various firefighting techniques, crisis management, and cooperation with other emergency services. Depending on the terrain and weather conditions, training in mountain and aerial rescue may also be necessary.
5	Fire Suppression	Training in firefighting is essential for rescue units and individuals responsible for workplace safety. It includes learning how to operate various types of extinguishers, techniques for extinguishing different types of fires, firefighting tactics, and proper situation assessment to avoid endangering human lives.
6	Protection from toxic substances	During firefighting in the woods, there is a risk of exposure to toxic substances such as smoke and fumes. Therefore, individuals participating in firefighting operations must be trained in the use of appropriate personal protective equipment and procedures for dealing with exposure to harmful substances.
7	Technologies and innovations	The development of technology can significantly impact the effectiveness of wildfire management and suppression efforts. Therefore, training should include learning how to operate modern equipment such as UAVs, satellites, and fire monitoring systems.
8	International cooperation	Wildfires do not stop at national borders, hence international cooperation in training and experience exchange is crucial. International organisations can play a key role in coordinating efforts and supporting countries in combating wildfires.

No.	Need	Description of need
9	Social Education	It is crucial to ensure that training is accessible to a wide range of people. In addition to firefighting and forestry services, training should also involve local communities. Social education and prevention play a key role in minimising the risk of wildfires, so there should be a strong emphasis on informing the public about hazards and proper safety procedures. Increasing public awareness of the risks associated with wildfires is essential for effective prevention. Therefore, training should not only target those directly involved in firefighting but also local communities, tourists, and political decision-makers.
10	Evacuation	Training on evacuation and securing property should be provided to local communities in the event of a fire. People should be trained in evacuation procedures, familiarity with escape routes, and ways of behaving in panic situations. These training sessions may comprise fire drills and demonstrating the appropriate actions in case of a real threat.

Source: own work on the basis of (Pimlot et al., 2014; Szajewska, 2018; CIFFC, 2022; Casartelli, Mysiak, 2023)

Training needs related to wildfires encompass both educating local communities and professional emergency services. Communities require knowledge about prevention, swift response, and safe practices during evacuation in case of a wildfire threat. Training for emergency services should focus on refining firefighting techniques, crisis management, and intersectoral collaboration. Additionally, learning to use modern monitoring technologies and tools is crucial to enhance the effectiveness of preventive and intervention actions. Below are the thematic scopes for specific training sessions derived from real needs.

Safety rules

Safety rules to be followed in the woods should be known and followed by all individuals who spend time in the forested areas. This includes both individuals working there and those visiting the woods for recreational purposes. Safety rules should be taught to young citizens as part of preschool education by educators. They should also be posted on signs at forest entrances.

Training on wildfire prevention

The training programme on prevention actions should provide participants with the knowledge, skills, and tools necessary to minimize the risk of wildfires and to react quickly in case of danger. Below are the topics that may be included in the training programme (Pimlot et al., 2014; Szajewska, 2018; CIFFC, 2022; Casartelli, Mysiak, 2023):

1) Hazard identification: This topic should begin with discussing the main factors contributing to wildfires, such as weather conditions, human activity, forest condition, and species composition. Participants should be trained to recognize potential hazards and factors increasing the risk of fire.
2) Prevention and education: This topic should include elements of prevention, including education on proper behaviour in the woods, safety rules during campfires, prohibition of grass burning, and the consequences of smoking. Participants should be aware of the consequences of their actions and ways to minimize the risk of fire. Legal consequences for violations should be emphasized according to the laws of the country.
3) Monitoring and detection of threats: This topic should cover the use of monitoring techniques to assess forest conditions and detect fire hazards, including early warning systems, UAV observation, and satellite technologies. Participants should be trained to identify alarm signals and respond quickly to them.
4) Planning of preventive actions: This topic should include elements of planning preventive actions, such as working with hazard maps, discussing protected zones, terrain marking methods, and familiarization with topography and firebreak locations.
5) Safety and evacuation procedures: Participants should be trained in safety rules during preventive actions and evacuation in case of a fire threat. The programme should include information on proper attire and equipment, alarm procedures, reporting fires, and evacuation procedures.
6) Social cooperation: A key element of the training programme should be teaching social cooperation in forest fire prevention. Participants should be encouraged to actively participate in local social initiatives aimed at promoting safe forest use and supporting forest and rescue services.
7) Schedule of subsequent trainings: The training programme should provide regular updates and enhancements of knowledge and skills to adapt

to changing weather, technological and social conditions. Participants should be encouraged to continue learning and actively participate in local prevention initiatives.

Preparing a training programme on wildfire prevention in this way can effectively increase public awareness of fire hazards and skills needed to deal with them, ultimately contributing to reducing the number of fires and minimizing their impacts.

Training on wildfire detection and monitoring

A training programme on wildfire detection and monitoring should be constructed comprehensively, encompassing theoretical lectures, practical exercises and field simulations. The main objective of such a programme is to train participants in effective methods of monitoring forest conditions and detecting fire hazards to enable quick response and minimise the impacts of fires. Following training forms and topics should be taken into account:

1) Theoretical lectures:
    a) Discussion of basic threats associated with forest fires and factors influencing their occurrence and development.
    b) Presentation of various methods for monitoring forest conditions, including the use of satellites, unmanned aerial vehicles (UAVs), and other electronic technologies.
    c) Operation of observation towers equipped with visual observation systems.
    d) Explanation of the operation principles of early warning systems and interpretation of fire-related data.
2) Practical exercises:
    a) Demonstration of the practical operation of various monitoring technologies, including calibration and equipment setup.
    b) Exercises on interpreting monitoring data and responding quickly to alarm signals.
    c) Simulations of fire situations and attempts to detect fires in various terrain conditions.
    d) Organization of field simulations allowing for the practical application of acquired knowledge and skills in realistic conditions.
    e) Fire detection using UAVs and other technologies in forest environments.
    f) Cooperation with other rescue services and participation in simulated firefighting actions.

3) Reporting and coordination procedures:
   a) Exercises utilizing various communication channels (radio, telephone, data and communications network).
   b) Training in documenting detected fire hazards and reporting data to relevant authorities.
   c) Exercises in coordinating actions between different rescue units and crisis management authorities.
4) Occupational health and safety (OHS):
   a) Introducing participants to occupational health and safety principles in the field, including appropriate attire, equipment and emergency procedures.
   b) Discussion of ethical and legal aspects of work related to monitoring and fire detection, including compliance with privacy and data protection principles.

The training programme on wildfire detection and monitoring should be flexible and tailored to the needs and capabilities of the participants, while ensuring comprehensive preparation for effective fire risk management in forest environments. Regular updates and enhancements to the programme are also crucial considering the rapidly changing technologies and terrain conditions.

Training on intervention and firefighting

The main objective of training on intervention in wildfires is to prepare participants for comprehensive action in fire hazard situations, including action planning, team coordination, crisis management and effective firefighting. The main goal of firefighting training is to impart practical skills related to extinguishing fires, such as the use of various tools and firefighting techniques, handling firefighting equipment and safe firefighting practices. While the thematic scope of both types of training is related, the main emphasis is placed on different topics. Training on intervention should include the following:

1) Theoretical lectures:
   a) Discussion of basic issues related to wildfires, including types of fires, factors influencing their development, and the consequences of fires for the natural environment and people.
   b) Presentation of various firefighting methods, including extinguishing agents, firefighting techniques, and tools used for firefighting.
2) Firefighting techniques:

   a) Practical exercises on using different methods and techniques for firefighting in the woods, including the use of water, foam, powder extinguishers, aerosols, or other extinguishing agents.
   b) Learning the proper operation and use of firefighting equipment, including fire hoses, handheld extinguishers, blowers, firefighting axes and other rescue tools.
3) Firefighting tactics:
   a) Discussion of principles for planning firefighting actions, including situation assessment, threat identification, resource allocation, and selection of appropriate firefighting methods and techniques.
   b) Coordination exercises in firefighting teams, including role division, cooperation with other rescue units, and communication in crisis situations.
4) Safety and emergency procedures:
   a) ABC of safety principles (including threatening chemical industry or trapped HAZMAT transportation in forest road).
   b) Introduction of participants to workplace safety principles during firefighting in the woods, including appropriate attire and equipment, emergency procedures, and securing the incident site.
   c) Training on alarm procedures, fire reporting, and response to emergencies and accidents.
5) Teamwork:
   a) Teamwork exercises during firefighting in the woods, including role division, cooperation with other rescue units, and coordination of actions in firefighting teams.
6) Crisis management:
   a) Discussion of crisis management procedures in wildfire situations, including organising actions, resource allocation, team coordination, and communication in crisis situations.
   b) Practical exercises in intervention action planning, including developing action strategies, risk assessment, and development of evacuation plans.
7) Social education:
   a) Discussion on the importance of social education in wildfire prevention and promotion of social awareness of fire hazards and the need for effective responses.
8) Schedule of subsequent trainings:

a) Providing participants with the opportunity to continue training by supplying educational materials, organising regular field exercises, and participating in skill-enhancing courses in firefighting and crisis management.

Protection against toxic substances

Training on protection against toxic substances in the context of wildfires must take into account specific hazards and procedures related to exposure to toxins during firefighting intervention. Below are topics that can be included in such training:

1) Definitions and classifications of toxic substances that may be faced by firefighters during firefighting interventions in the woods.
2) Routes of exposure to toxins during wildfires and types of toxic effects.
3) Most common toxic substances released during wildfires, such as carbon monoxide, nitrogen oxides, aldehydes, chlorine compounds and volatile organic compounds.
4) Impact of fire smoke on human health, symptoms of poisoning, and long-term effects of exposure.
5) Risk assessment related to exposure to fire smoke and toxic substances.
6) Personal protective equipment used during firefighting interventions in the woods, such as dust masks, filtering masks, protective clothing.
7) Procedures in case of exposure to toxic substances during firefighting intervention in the woods.
8) Alarm procedures, first aid, and evacuation in case of contact with toxic substances.
9) Planning and conducting evacuation from the fire site in case of danger posed by toxic substances.
10) Personnel decontamination procedures after firefighting interventions, including removing contaminants from clothing and equipment.
11) Principles of safe firefighting in conditions of exposure to toxic substances.
12) Prevention of poisoning and minimisation of exposure risk through proper use of personal protective equipment and avoidance of exposure to fire smoke.
13) Field exercises and simulations of firefighting actions in realistic conditions, taking into account exposure to fire smoke and toxic substances.
14) Practical exercises involving protective equipment and procedures in case of exposure to toxins.

Including these topics in training will better prepare firefighters to operate in challenging fire conditions, minimising the risk of exposure to toxic substances and ensuring effective protection of the health and lives of rescuers.

Technology and innovation

Training on technology and innovation should focus on utilising modern tools and technologies for preventing, monitoring, combating and managing wildfires. Here are some examples of topics that could be included in such a training:

1) Forest fire monitoring systems:
   a) Utilising satellites, UAVs (Unmanned Aerial Vehicles), and electronic sensor systems to monitor the wooded areas for fire outbreaks.
   b) Early warning detection technologies: analyses of spectroscopic images, thermal sensors, networks of ground sensors.
2) Modelling and forecasting of fires:
   a) Using mathematical models, Fire Weather indexes and computer simulations to forecast the spread of wildfires.
   b) Predictive algorithms for fire hazards based on atmospheric conditions, terrain topography and vegetation type.
3) Communication and crisis management systems:
   a) Using GIS (Geographic Information Systems) for managing wildfire data and coordinating intervention actions.
   b) Communication platforms and mobile applications for quick dissemination of information about fires, evacuations, and safety.
4) Modern firefighting technologies:
   a) Innovative methods for extinguishing wildfires, such as using UAVs for monitoring or helicopters with water sprinkling systems and/or water bombing systems.
   b) Utilising automatic monitoring systems for the wooden areas and responding to fire outbreaks.
5) Simulation programme operation:
   a) Virtual training in crisis management and firefighting interventions for wildfires, enabling realistic simulations of different fire scenarios.
   b) Using VR (Virtual Reality) and AR (Augmented Reality) technologies for practical training in extinguishing forest fires.
   c) Simulations of total forest fires in simulation programmes.
6) Social education and awareness of risks:
   a) Utilising social media, streaming platforms, and mobile applications for social education about wildfire risks and prevention methods.

   b) Information and educational campaigns using interactive multimedia, 360-degree videos, and simulation games.
7) Modern data analysis methods:
   a) Analysing data from sensors, detectors, and monitoring systems to identify trends, patterns and factors influencing the risk of wildfires.
   b) Using machine learning algorithms to analyse large datasets related to wildfires and develop predictive fire risk models.
8) Utilisation of thermal imaging:
   c) Familiarisation with the physical properties of infrared observations.
   d) Operation and optimal use of thermal imaging cameras in various situations.

Training courses of this kind should be organised to keep up with the acquisition of new technologies so that they can be implemented into daily use as quickly as possible. A common mistake made by decision-makers is to save expensive modern equipment for fear of damage. As a result, staff trained to operate it are limited in number and the equipment is not fully utilised.

International Cooperation

Training related to international cooperation should aim to prepare participants for effective collaboration and coordination in preventing, monitoring, combating, and managing wildfires on an international scale. Training sessions may cover various areas of cooperation. Below are potential areas of international cooperation activities for which training should be conducted concurrently:

1) Essential trends in wildfires:
   a) Assessment of the scale and frequency of wildfires worldwide.
   b) Identification of the main factors influencing the occurrence of wildfires on different continents.
2) International regulations concerning wildfires:
   a) Review of international agreements, conventions, and agreements concerning the protection of the woods from fires.
   b) Analysis of the role of various international organisations in coordinating actions related to wildfires.
3) Common standards and protocols:
   a) Development of common operating standards and intervention protocols for firefighting activities in various countries.
   b) Discussion of best practices in preparation, response, and management of wildfires at the international level.

4) Technologies and tools for monitoring of wildfires:
   a) Overview of modern technologies, such as satellite monitoring systems, UAVs, ground sensors, used for monitoring wildfires on a global scale.
   b) Discussion of the potential use of fire monitoring data for joint analysis and forecasting of hazards.
5) National and regional cooperation:
   a) Analysis of models of international and regional cooperation in combating wildfires.
   b) Case studies of successful joint actions and initiatives in the field of fire risk management.
6) International education and training:
   a) Familiarisation with educational and training programmes related to wildfires carried out in different countries.
   b) Discussion of educational strategies and informational campaigns aimed at raising public awareness of fire hazards.
7) Communication and information exchange:
   a) Familiarisation with communication tools and platforms used for exchanging information about wildfires between individual countries.
   b) Discussion on effective communication strategies in the event of international fire crises.
8) International exercises and simulations:
   a) Organisation of international exercises and simulations aimed at preparing for joint action in crisis situations.
   b) Utilisation of simulations to identify areas requiring further improvement and development of international cooperation.
9) Data management and risk analysis:
   a) Discussion of methods for collecting, processing and analysing wildfire data at the international level.
   b) Use of risk analysis to identify areas most vulnerable to fires and to plan preventive actions.
10) Review of international support measures:
   a) Presentation of options for financial and logistical international support in the event of wildfires.
   b) Discussion of procedures and mechanisms of operation of international organisations in providing assistance to countries affected by wildfires.

Training should be delivered in an interactive manner, incorporating discussions, case studies, and practical exercises to enable participants to apply the acquired knowledge and skills effectively. It is also important to emphasize the significance of international cooperation.

Training on social education

Training on social education in the context of wildfires aims to raise general awareness about fire hazards and promote attitudes and behaviours conducive to preventing fires and responding appropriately in case of their occurrence. Topics may encompass various aspects related to wildfire protection and can be addressed at different social groups:

1) Analyses of causes and effects of wildfires.
2) Discussion of factors increasing the risk of fires.
3) Emphasizing the importance of community involvement in preventive actions.
4) Strategies promoting active community participation in fire prevention.
5) Link between wildfires and environmental conservation.
6) Promotion of actions conducive to sustainable forest use.
7) Principles of safe use of wooded areas: grilling, campfires, camping.
8) Guidelines for avoiding behaviours that could lead to fires.
9) Identification of warning signs indicating the possibility of a wildfire.
10) Training in rapid and effective response in case of a fire.
11) Informing the community about action plans in case of a wildfire.
12) Building public trust in the actions taken by rescue services.
13) Explanation of alarm and evacuation procedures in case of a wildfire.
14) Education on available crisis communication methods and their importance.
15) Planning and implementation of educational campaigns on wildfires.
16) Utilisation of social media, posters, radio and television spots to promote safe practices.
17) Promoting cooperation among different social sectors in social education on wildfires.
18) Building interaction between local authorities, non-governmental organisations, the private sector, and the local community.
19) Methods for assessing the impact of educational activities on social awareness and behaviour change.
20) Monitoring the effectiveness of social campaigns and adjusting strategies based on evaluation results.

It is important for the training to focus not only on imparting information but also on developing practical skills and motivating participants to become actively engaged in actions for safety and security in the woods.

Evacuation

Evacuation training should focus on preparing participants to leave fire-prone areas quickly and safely and teaching them appropriate procedures and behaviours in crisis situations. Training topics may comprise the following thematic areas:

1) Assessment of the risk associated with wildfires: atmospheric factors, terrain topography, and type of vegetation.
2) Identification of potential hazards during evacuation.
3) Evacuation plans for areas threatened by wildfires.
4) Evacuation routes to assembly points.
5) Discussion of procedures for alerting the community about a wildfire threat.
6) Clarification of different warning and alert systems, such as sirens, SMS notification systems, radio alerts.
7) Training on how to react to a wildfire alarm (remaining calm, organising prompt evacuation).
8) Discussion on procedures for contacting emergency services and providing information about the on-site situation.
9) Instruction on safe evacuation techniques in the wooded terrain: avoiding steep slopes, crossing streams, navigating around fires.
10) Education on identifying safe shelter locations in the event of rapid-fire spread (safety zones).
11) Tips for packing essential items for evacuation: documents, medications, water and food supplies.
12) Training concerning preparing for evacuation in conditions of limited visibility caused by smoke.
13) Organisation of the evacuation of persons with disabilities and children.
14) Procedures for special care for persons with disabilities and children during evacuation.
15) Discussion of available transportation options for people with mobility impairments.
16) Communication during evacuation.
17) Guidance on maintaining communication with other family members and emergency services during evacuation.

18) Training on the use of mobile phones and other communication means in emergency situations.
19) Organisation of evacuation simulations in a wooded terrain or using virtual simulators.
20) Practical exercises on safe navigation in wildfire conditions and making decisions in crisis situations.
21) Training on securing households (home sprinkler systems, equipping with ladders, etc.).

Training courses should be tailored differently depending on the area in which they are to be conducted, taking into account local conditions. The thematic scope should be tailored to training recipients (different ones for residents living in the wooded areas than for those living in cities).

2.2. Training participants

Training programmes related to wildfires should be tailored to various social and professional groups that may influence fire prevention, management and suppression efforts. Below are the groups that should be covered by different training programmes:

1) **Emergency services:** Firefighters, mountain rescue teams, forestry workers, and other units responsible for firefighting should undergo regular training in firefighting techniques, crisis management and collaboration with other emergency services.
2) **Forestry workers:** Individuals working in forestry, including foresters, forest rangers, forestry administration staff and volunteers, should be trained in fire prevention, forest monitoring, and emergency response procedures in case of a fire.
3) **Local communities:** Residents of nearby the wooded areas, including farmers, livestock breeders and property owners, should be educated about the risks associated with wildfires and appropriate safety procedures and evacuation.
4) **Tourists and vacationers**: Individuals visiting the woods for recreational purposes should be informed about safety rules and potential consequences of careless behaviour that could lead to wildfires.
5) **Officials**: Individuals responsible for formulating environmental protection and crisis management policies, including local and regional officials,

should be aware of the need to invest in fire prevention and intervention related to wildfires.

6) **Forest industry:** Companies operating in the forestry sector play a significant role in forest management and fire risk minimisation efforts. Training for business representatives and the forestry industry can focus on sustainable forest management strategies, the use of fire prevention technologies, and risk management associated with activities in the wooded areas.

All these mentioned social groups have real training needs regarding wildfires, which can be met via appropriately tailored educational and training programmes, taking into account the specific nature of their activities and the latest scientific and technological developments in crisis management and environmental protection. All these groups have their unique needs and challenges related to fire hazards, so it is important to adjust training programmes to the specifics of their activities and consider diverse perspectives and experiences in managing these events.

Not every training needs to be organised by entities with the appropriate knowledge base, experts and high qualifications. Basic fire safety training should be conducted as early as preschool and should be included in the educational programme for children. Social education training can be conducted by NGOs and educational institutions. Specialised training, especially regarding intervention and firefighting, should be delivered by organisations with experts. Below is a list of potential entities capable of organising a training:

1) **Environmental protection agencies:** Government agencies responsible for environmental protection often organise wildfire training because they are key entities in crisis management and preventive actions.
2) **Fire brigade:** Firefighting units, both at the local and regional or national levels, often organise training for their employees and for local communities in wildfire management (particularly in wildfire response).
3) **Non-governmental organisations:** Local NGOs, environmental protection associations, or community groups may engage in organising wildfire training, especially if they operate in areas threatened by this phenomenon.
4) **Educational and scientific institutions:** Universities, colleges and scientific institutions often conduct research and organise training in ecology, environmental protection and crisis management, including wildfires.

5) **Training companies:** Training companies specialising in fire safety can offer equipment and software services to clients from the public, private and NGO sectors.
6) **International organisations:** International organisations such as the United Nations, the International Union for Conservation of Nature, or the World Meteorological Organisation, may organise wildfire training for their members and partners from different countries.
7) **Forest industry companies:** Companies operating in the forestry sector, including forest management, timber industry, or commercial enterprises, may organise forest fire training for their employees and for local communities in the areas under their management.

These entities can organise various types of training, from informational sessions and practical workshops to evacuation simulations and field exercises, to impart the knowledge and skills needed for effective wildfire management.

2.3. Training equipment

During the implementation of a firefighting training programme, a variety of equipment is used to assist participants in practical skill enhancement and simulating real-life situations. Depending on whether the training is field-based or theoretical, various tools may be utilised, such as for example computer simulation.

Advanced computer simulation systems allow simulating wildfires as well as intervention and crisis management actions. Participants can practice various scenarios and make decisions in conditions similar to actual ones. Popular programmes include the **Wildfire Simulator**, a simulation tool that allows simulating wildfire spread in various terrain and weather conditions. It is used for firefighter training, fire dynamics research, and planning preventive actions. Another example is the **FARSITE** software developed by the USDA Forest Service. It is an advanced computer tool that enables simulating fire spread over large afforested areas and assesses its impact on the environment. FARSITE is used for firefighting planning, fire behaviour prediction and risk analysis. Most simulation programmes are based on fuel models, predicting burning time based on maps with specific fuel types for the region. However, since fuel types vary significantly in different regions, there is legitimate concern that the adequacy of simulated fires may vary greatly from actual fires. It is worth noting that the adequacy of simulating total fire is higher than simulating surface fires, which are less predictable (Szajewska, 2018; Szajewska, 2024).

Simulating fires has the advantage over controlled burning in that it does not generate any costs to obtain knowledge about fire spread or unnecessary risk. Trained personnel can gain a general idea of fire development and various firefighting tactics. However, the degree of adaptation of fuel models to a given region and the adequacy of simulation to the real situation are significant drawbacks. Model limitations suggest that the programme cannot simulate realistic fire perimeters (Zinger et al., 2020). Other examples of simulation programmes include **FLAMMAP** (Flame Length and Spread Model) and **Prometheus**. All these simulators are used to improve firefighting and fire risk management skills (Szajewska, 2018; Szajewska, 2024).

In addition to fire development simulators, there are also fire simulators that generate a subjective image for the observer through computer animation. These simulators generate various terrain conditions and types of fires, allowing for diversified training. Such training moderately reflects realistic conditions of a real fire, providing a preliminary insight into the situation for the trainee. Firefighter Training Software and Firefighting Simulator are examples that can utilise virtual reality (VR) animations for firefighter training:

1) **Firefighter Training Software:** Some versions of Firefighter Training Software offer the possibility of using virtual reality to conduct fire simulations and interactive exercises. Users can use VR devices, such as VR goggles, to immerse themselves in fire situations and practice their skills in realistic virtual scenarios.
2) **Firefighting Simulator:** Firefighting Simulator is dedicated software for fire simulation designed for use in virtual reality. It allows firefighters to practice firefighting exercises in a three-dimensional virtual environment, enabling realistic and immersive training in safe conditions.

In both cases, the use of virtual reality allows firefighters to become better prepared for real fire situations through practice in a controlled environment, where they can improve their firefighting skills, coordinate rescue actions, and make decisions under high-stress conditions.

Imaging systems are increasingly being utilised with UAVs. UAVs are equipped with visible light cameras as well as thermal imaging cameras. These sensors can be used for monitoring and observing wildfires from the air, as well as for locating people and animal habitats. During training sessions, they can be used to simulate aerial monitoring activities and coordinate rescue efforts. For heavier UAVs in the EU, pilots are required to have the appropriate category qualifications for operation. Specialised training courses for UAV operation are conducted for this purpose, culminating in the issuance of a certificate for a specific category. Most UAV flights are controlled within the line of sight between the pilot and the UAV. Typical applications comprise (Feltynowski, Zawistowski, 2018; Szajewska, 2020; Fellner, 2023):

1) **Fire monitoring:** UAVs can be deployed to monitor wildfires, buildings or industrial areas. With thermal and visual cameras, firefighters can obtain a realistic aerial view on the situation, enabling a better understanding of the size and dynamics of the fire.
2) **Search and rescue:** UAVs can assist in the search for missing or trapped individuals in hard-to-reach areas, which is particularly important during evacuations or rescue operations.
3) **Terrain monitoring:** By conducting flights over the terrain, UAVs can provide information about terrain conditions, topography, evacuation routes, hot spots (generated by high intensity fire) or water sources, which are crucial for effective crisis management.
4) **Support in rescue planning:** Images and data collected by UAVs can be used to plan rescue strategies, including the location of firefighting points, evacuation routes, and optimal access routes for rescue vehicles, as well as observations of fire development.

There is currently a strong demand for training in the use of UAVs in rescue operations. The reason for such high interest is the speed of response. UAVs can be quickly deployed into the air, providing a rapid aerial view of the situation. Until recently, bird’s-eye-view imagery was only possible through aerial photography. Another reason is the availability of technology that was previously reserved for the military sector. UAVs are essential tools in firefighting training, allowing skill enhancement, better situational understanding, and effective planning and coordination of rescue operations.

In addition to modern technology, exercises utilise equipment available in fire departments such as (i.a.):

a) radio communication systems (radios),
b) firefighting off-road vehicles,
c) quads,

d) piston pumps,
e) fire extinguishers,
f) ropes and lances,
g) fire hoses,
h) axes and chainsaws for tree removal,
i) water transfer pumps,
j) water containers,
k) robots,
l) detectors,
m) tele-communication devices.

The specified equipment items are often deployed during wildfire extinguishing exercises and assist firefighters in executing effective rescue operations in the woods. They are the everyday tools of a firefighter, so regular training and practice with this equipment is important to ensure high efficiency and safety during real interventions. The choice of specific training equipment depends on training objectives, available resources, and the nature of the given situation. It is important for the equipment to be properly adapted to training needs and to allow realistic simulations and practical exercises that contribute to the effective improvement of participants' skills.

Chapter 3. Training guidelines for preparation and pre-planning activities for wildfire response

3.1. SILVANUS approach on systematic methodology for the preparation and pre-planning activities for wildfire response

The SILVANUS project represents a significant step forward for preparation and pre-planning activities for wildfire response. The project "(…) 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" and it is to "(…) cater to the demands of efficient resource utilisation and provide protection against threats of wildfires encountered globally" (SILVANUS, 2021). The project establishes synergies between three essential dimensions of wildfire management determinants: (a) environmental issues, (b) technologies, and (c) social science knowledge. It is to enhance the ability of wildfire management authorities to monitor resources of the woods, evaluate biodiversity, compile information about accurate fire risk indicators and promote safety standards, regulations and good practices among citizens (the users of the woods and other stakeholders). The project novelty stems from development and integration of (a) advanced semantic technologies, (b) knowledge of forest administration, and (c) resource utilisation. The platform is to establish a big-data processing framework for analyses of heterogeneous data sources (earth observation resources, climate models, weather data, etc.) and executing on-board computation processes to obtain a common situational picture for all entities involved in wildfire management processes. To achieve this goal, the project allows integration of multiple sensors connected by effective and robust communication network. The project technological layer is made up of ground and air solutions, and their practical use gives input to effective reconstruction and recovery of forests after a wildfire (SILVANUS, 2021).

The SILVANUS project covers all phases of wildfire management. Thus, it refers also to preparation and pre-planning activities. Those phases are illustrated in Figure 17.

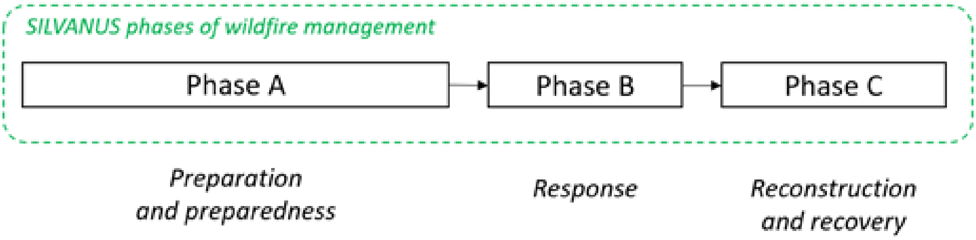


Figure 17. Phases of wildfire management

Source: own study

Phase A means preparation and preparedness, including preparation and pre-planning activities for wildfire response. This is the initial phase of wildfire management. As a rule, relevant activities are conducted before fire materialisation. Special attention is paid to deployment of multiple sensors, computational tools, decision support systems, and edge technologies to shape situational picture and to be ready for picture modifications while a danger occurs. A very important issue is to effectively prepare wildfire responders to notify of the hazard as well as to use skills, equipment and infrastructure they have to operate in disaster conditions. Phase B starts when a wildfire breaks out. It is related to performance of technological interventions developed and deployed for the early-stage detection of wildfire ignition. This implies direct use of multiple technologies to increase situational awareness and support wildfire responders. Phase C, on the other hand, is related to reconstruction and recovery processes and comprises post fire rehabilitation of land. Forest resources are a key point in reconstruction and recovery processes. All technologies deployed are to monitor these processes as well as to give information valuable from the perspective of effective rehabilitation.

The general use of multiple technologies in the SILVANUS approach is presented in Figure 18.

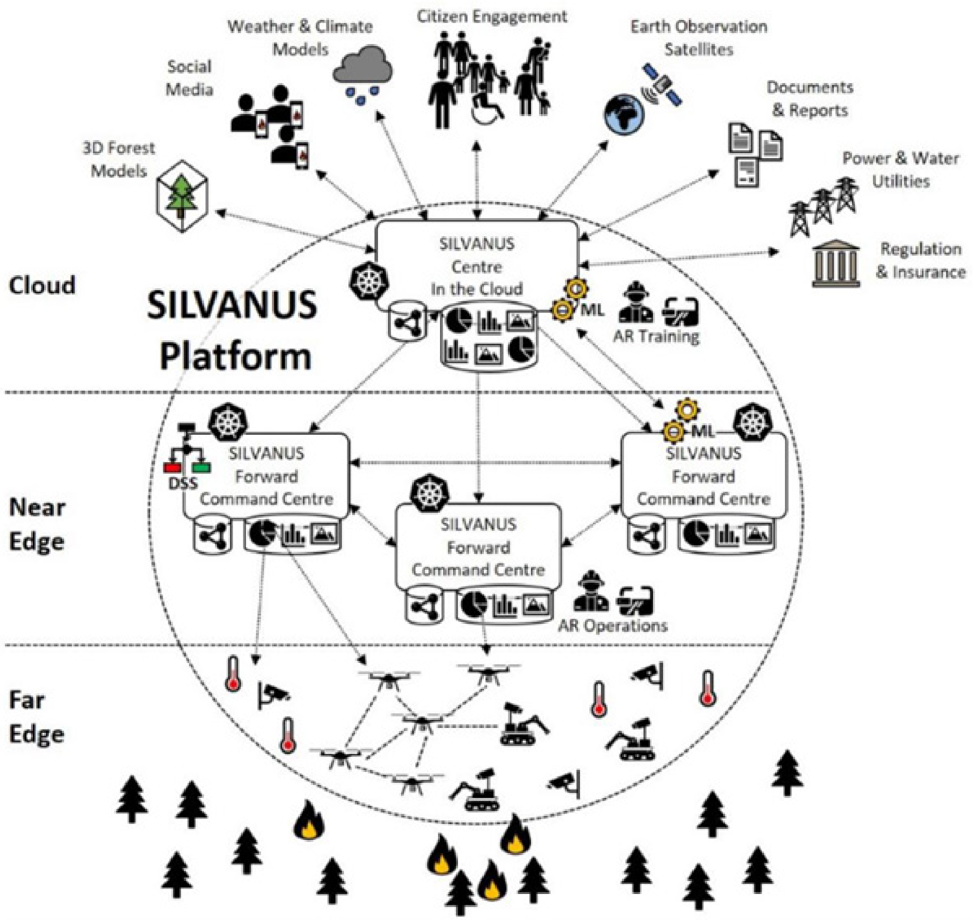


Figure 18. General illustration of the SILVANUS approach

Source: (Mojir et al., 2023)

The use of technologies is common for all wildfire management phases and may be divided into cloud implementation, near edge implementation and far edge implementation. This means that some of technological functionalities to support preparation and pre-planning activities require to be used directly on the wildfire scene (for example robots, drones), some of them can be deployed in safety distance (command centres, etc.), and the rest are implementable to the cloud (i.a. decision support systems). This type of approach makes the preparation and pre-planning activities flexible and adjustable to current situational picture and operational needs of wildfire responders.

It is worth highlighting that the SILVANUS project pays particular attention to preparation and pre-planning activities for wildfire response. Task 3.3 of the project concerns directly this issue. The task objective is to propose a systematic methodology for the preparation and pre-planning activities to be carried out upon the ignition of forest fires. Consequently, the activities are ascribed directly into the general project idea and cross-cut many other project tasks. It is schematically presented in Figure 19.

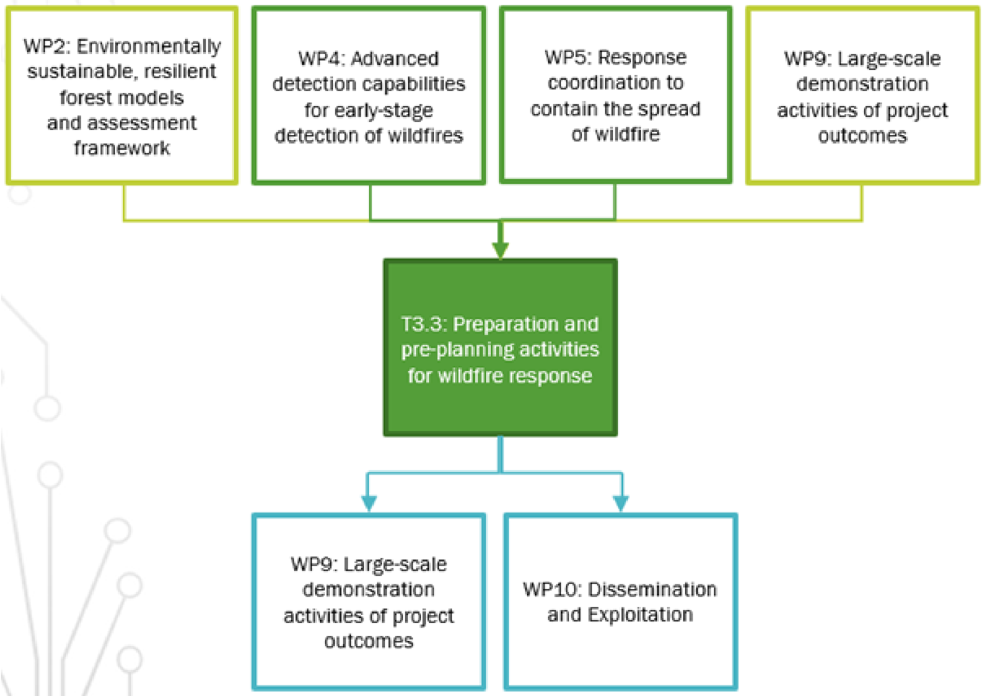


Figure 19. Preparation and pre-planning activities for wildfire response in the SILVANUS approach

Source: (SILVANUS T3.3, 2022)

Connections between T3.3 and other project work packages determine the way in which preparation and pre-planning activities are designed and conducted. The activities are based on a wide information framework on environmentally sustainable, resilient forest models and assessment. They are related to advanced detection capabilities for early-stage detection of wildfires and reflect response coordination to contain the spread of wildfire. A particular important point is to make them useful for stakeholders, including end-users of SILVANUS technologies. This justifies the close relation of preparation and pre-planning activities to project pilots and demonstrations, similarly as verification of relevant conditions and ideas in dissemination and exploitation processes. All this to create a set of chances to confront T3.3 results with stakeholders (especially firefighters and other wildfire responders).

As regards phase A of wildfire management and project objectives, T3.3 is to provide input to enhancement of the following:

a) wildfire prevention and management tactic methodologies and procedures using the progressive ICT tools,
b) training handbook for fire fighters on the safety regulations for the deployment of technologies,
c) development of a semantic framework to formalise the stakeholder involvement in sustainable forest management,

as well as to define training activities designed to improve safety and preparedness of firefighters in combating wildfire.
This emphasizes that essential issue of preparation and pre-planning activities for wildfire response due to the SILVANUS approach is training.

In association with T3.3 results, the systematic methodology for preparation and pre-planning activities to be carried out following the occurrence of forest fires is based on the following assumptions:

1. Training is the only kind of activity able to effectively transfer the wide spectrum of wildfire-related information to relevant responders and, simultaneously, to implement new technologies and ensure safety of trainees (in accordance to wildfire specifics).
2. The methodology should express fundamental educational issues such as:
   a) training content (data, information, skills),
   b) training objectives,
   c) training forms and methods,
   d) training materials.
3. The methodology needs to consider all technologies developed in the SILVANUS project and give guidelines on how to use them in training processes.
4. The use of technologies should be reflected in reference training protocols to make them operational and adjustable to multiple training needs.

5. Facing requirements of end-users forces ensuring that training protocols must reflect overall process of wildfire response.

As far as these assumptions are concerned, the systematic methodology for the preparation and pre-planning activities to be carried out after ignition of forest fires can be presented in the step-by-step formula illustrated in Figure 20.

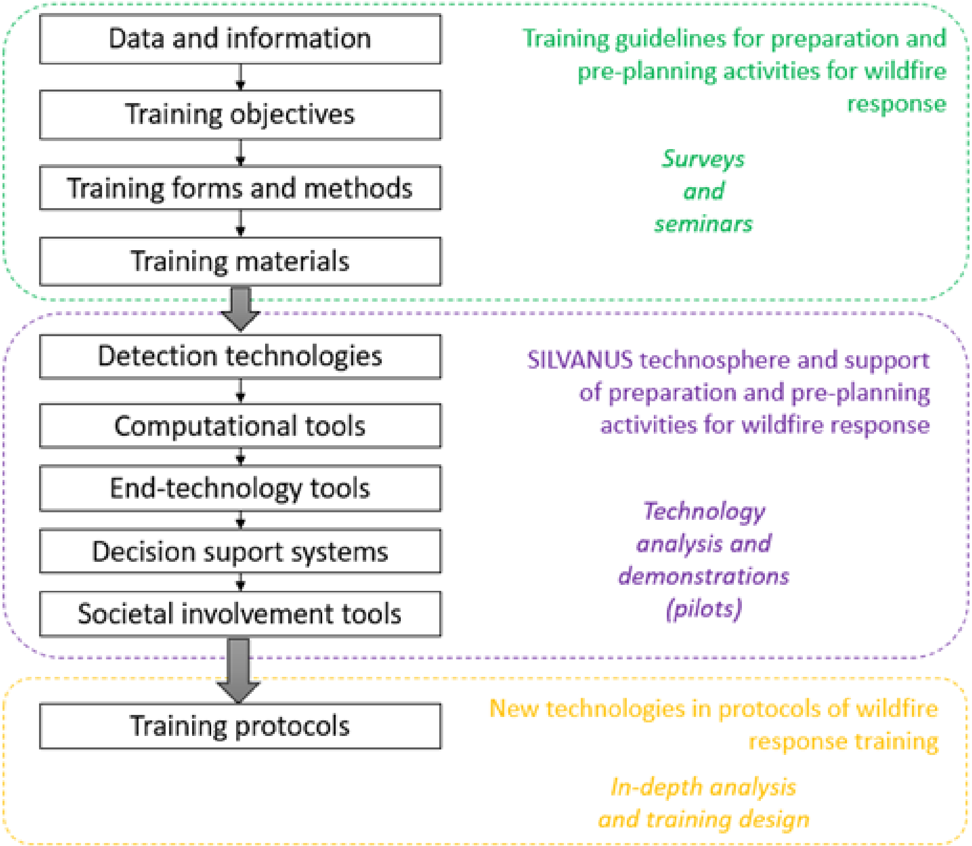


Figure 20. Systematic methodology for preparation and pre-planning activities to be carried out after ignition of a forest fire

Source: own study

Gathering training guidelines for preparation and pre-planning activities for wildfire response requires involving experts who are able to concretise what, when, where, for who and how should be done when planning and delivering the training. The reference forms of their involvement are surveys and seminars. The surveys provide an opportunity for unhindered reflection of own ideas and insights. The seminars can play a significant role in operationalisation of information collected and in-depth analysis of survey results. Relevant results should be detailed information about data and information (as crucial resources in pre-planning and preparation activities for wildfire response), training objectives, training forms and methods, and training materials.

Technology analyses and demonstrations (pilots) are reference ways to investigate and validate new solutions and tools to support pre-planning and preparation activities for wildfire response. As regards the SILVANUS project, detection technologies, computational tools, end-technology tools, decision support system and citizen engagement tools need to be taken into account. All of them should be analysed not only from the viewpoint of direct deployment to wildfire response but also from the perspective of training processes. This allows creating a background for comprehensive use of the tools and solutions before and during the response, and also ensures effective manual and maintenance preparedness of wildfire responders.

Reference training protocols are said to be the final outcome of the methodology. To ensure their rationality and operationality, it is necessary to reflect particular phases of the wildfire response, namely (a) early detection and communication of the hazard, (b) immediate dispatch of wildfire responders, (c) effective delivery of resources to the wildfire scene, (d) comprehensive reconnaissance of the hazard situation, (e) firefighting tactics, and (f) cooperation between firefighting entities. This should be done in line with an in-depth analysis and training plans to reflect specifics of wildfire phenomenon and response, assumptions for training related to preparation and pre-planning activities for wildfire response and training guidelines and training technosphere.

In conclusion, training seems to be the most universal and appropriate form for preparation and pre-planning activities in wildfire response when considering wildfire specifics, the response process, common use of modern technologies, and focusing of effectiveness. Training guidelines for wildfire response preparation and pre-planning activities should be determined by data and information presented, as well as training objectives, forms and methods and materials. Special attention should be paid to new technologies to support wildfire responders. Their analysis needs to consider training rigour and capacity. The final outcome of the methodology comprises a set of training protocols that uniquely connect operational needs related to a wildfire and new technologies into the training framework.

The SILVANUS methodology is a relatively universal framework for entities involved in wildfire response preparation and pre-planning activities. It may be tailored to current expectations and needs. Specific results of its implementation are presented in this monograph.

3.2. Data and information as crucial resources in wildfire response pre-planning and preparation activities

Data and information are crucial resources in pre-planning and preparation activities. This regards all phases of these activities that may be grouped into: (a) early detection and communication of the hazard, (b) immediate dispatch of wildfire responders, (c) effective delivery of resources to the wildfire scene, (d) comprehensive reconnaissance of hazard situation (from the ground and the air), (e) firefighting tactics, and (f) cooperation between firefighting entities. Based on literature review (paying special attention to operational procedures, research papers, good practices), listed below are focus group meetings, consultation with environment engineering specialists and consultation with the chief of GFFFV (Ground Forest Fire Fighting Using Vehicles) group from the Main Headquarters of the State Fire Service (Poland), relevant data sets and information required for the needs of pre-planning and preparation activities for wildfire response:

1. **Regarding early detection and communication of the hazard:**
   1) Access to early detection system (name of the system, its functionalities, data accessible, reliability): particle detectors (PM10, PM2.5), GSM localizers, crowd (social) sourcing (platform X, Facebook), temperature detectors, pyrotechnic cartridges, etc.
   2) Exact location of hazard.
   3) Number of wildfire sources/hot-spots.
   4) Area of the danger zone (covering a range of flames and smoke and site of the fire).
   5) Weather conditions (Wind Force and direction, insolation, Temperature and Relative Humidity Relationships, Atmospheric Stability, Lapse Rates, Large Scale Circulation, Air Masses and Fronts, General Winds, Convective Winds {Land & Sea Breezes, Whirlwinds, Slope and Valley Winds}, Thunderstorms and Clouds).

6) Vegetation type (for example: pine, spruce, 20-year-old forest, 50-year-old forest). Adaptation of a suitable fuel model.
7) Forest conditions (type of combustible material, litter moisture).
8) Presence of wildfire manifestations and cascading threats (for example: smoke, critical infrastructure objects, limited visibility).

2. Regarding immediate dispatch of wildfire responders:

1) Quality and quantity of wildfire responders in dispatch.
2) Quality and quantity of equipment to fight wildfires (including specialized devices, UAVs).
3) Road conditions (communication network, accessibility of roads).
4) Physical access to fire zone.
5) Permission for UAVs flights.
6) Aircraft flight ceiling and limitations of the use of aerial means that cannot fly in the presence of extreme wildfires.
7) Places of take-off and landing in rural areas (close to a fire front).
8) Schedule of water supply flights.
9) Location of reliable water supply points.
10) Access to water of appropriate quality (amount of water, efficiency of water supply source, current conditions of the water source): lakes, rivers, hydrants etc.
11) Location of reliable extinguishing points.
12) Location of reliable fire defence lines.
13) Location of mobile water supply points.
14) Possibility of additional supply of water.

3. Regarding the effective getting of the resources to the wildfire scene:

1) Road conditions (communication network, accessibility of roads).
2) Suggested access roads.
3) Access roads for tanks.
4) Physical access to fire zone.
5) Permission for UAVs flights.
6) Aircraft flight ceiling and limitations of the use of aerial means that cannot fly in the presence of extreme wildfires.
7) Location of reliable water supply points.
8) Location of reliable extinguishing points.
9) Location of reliable fire defence lines.
10) Location of mobile water supply points.

11) Mass evacuation conditions (evacuation routes, traffic jams, traffic management, detours).
12) Landform.

4. **Regarding the comprehensive reconnaissance of hazard situation (from ground and air):**
   1) Access to field communication system (name of system, its functionalities, data accessible, reliability): radiotelephones, satellite phones, etc.
   2) Communication structure (everyone knows when, how and to whom to communicate).
   3) Geo-localization of people in danger zone (firefighters, outsiders).
   4) Number and location of fire sources/hot spots.
   5) Current range of danger zone.
   6) First prediction of wildfire development (incl. fire front size, fire line intensity, direction, speed).
   7) Adequacy of emergency resources arrived.
   8) Information from fire warning towers to observe signs of fire (smoke, flames, glow etc.) from above the trees (in visible light, infrared).
   9) Information from satellite services (Landsat, Copernicus, Sentinel etc.)
   10) Land relief.
   11) Presence of wildfire manifestations and cascading threats (for example: smoke, critical infrastructure objects, limited visibility).
   12) Results of verification of preliminary information.
   13) Firefighting action status.

5. **Regarding firefighting tactics:**
   1) Location and structure of fire defence lines – if any. Location of potential defence lines for ad-hoc construction.
   2) Needs related to quality and quantity of extinguishing agents.
   3) Quality and quantity of extinguishing agents accessible.
   4) Possibility of using salt water, fire retardants agents, firefighting foams (due to environment protection).
   5) Current accessibility of equipment required.
   6) Alternativeness of equipment.
   7) Terrain height differences for needs of water supply organization.
   8) Access to international emergency mechanisms (e. g. Union Civil Protection Mechanism modules and rescEU capacities, bilateral).

9) Access to other security entities (for example: armed forces, border guard, police).
10) Prediction of wildfire development.
11) Fire engines tracking and visualization system.
12) Firefighting aerial means tracking and visualization system.
13) Acquisition of updated meteorological data in the fire area.
14) Fire characteristics and behaviour (e.g., fire line intensity, rate of spread, spotting activity, and distance).

6. Regarding cooperation between firefighting entities:

1) Access to international emergency mechanisms (e.g., Union Civil Protection Mechanism modules and rescEU capacities, bilateral).
2) Access to other security entities (for example: armed forces, border guard, police) and to the National Emergency Health Centre (for ambulances, hospitals, etc.).
3) Access to field communication system (name of the system, its functionalities, data accessible, reliability): radiotelephones, satellite phones, etc.
4) Communication structure (everyone knows when, how and to whom to communicate).
5) Geo-localization of people in the danger zone (firefighters, outsiders).
6) Prediction of wildfire development, mainly via fire spread simulation models.
7) Common operational picture (staff knows who is working where).
8) Command structure – who is in charge, who is coordinating.
9) Available radio frequencies for foreign teams.
10) Forest fire management plans are followed.
11) Demarcation of aircrafts water intake area and prohibition of approaching by civilians.
12) Fire characteristics and behaviour (e.g., fire line intensity, rate of spread, spotting activity, and distance).

It is worth highlighting that some of the data and information are required for more than only one phase of the wildfire response. Continuity of information flows gains in importance to assure that the situational picture is updated and every wildfire responder bases on the same operational assumptions.

3.3. Training objectives

Training objectives represent the training delivery directions. Objectives should be verifiable during the training. In turn, scope means information shared and/or gained during the training regarding the given objective. The objectives and the scope should be formulated in detail to set specific expectations for the training. Training objectives mean general educational directions to be followed during wildfire response preparation and pre-planning activities. They are closely related to the training scope as the scope is a kind of derivative of the objectives.

Training objectives and scope were specified within the first survey sent to all partners from Task 3.3 in the SILVANUS project and also discussed during the First International Scientific Seminar on Preparation and Pre-Planning Activities for Wildfire Response “Objectives and Scope of the Training” (29 June 2022). The main goal of the survey method was to identify objectives and scope of training for fire services, forest services, UAV operators and public administration representatives involved in wildfire response. Responders were informed that the training scope should cover operations to be carried out during the first period after wildfire ignition, ascribing into early detection and communication of the hazard, immediate dispatch of wildfire responders, comprehensive reconnaissance of the hazard situation (from the ground and the air), effective delivery of the resources to the wildfire scene, firefighting tactics (including ensuring continuous access to water) and cooperation between firefighting entities. Special attention was paid on the use of modern technologies (including AR/VR) as well as best organisational, equipment and tactical solutions.

Table 7 presents results of the information collecting process on training objectives and scope regarding early detection and communication of the hazard.

Table 7. Training objectives and scope for early detection and communication of the hazard

No.	Training objectives	Training scope
1	To acquaint the fire service with early detection system in a country they represent to be able to deploy it in practice and to follow detection procedures.	Scheme and description of national early detection system. Specific detection procedure for fire service from ground and/or from the air. Information on Fire Weather Index.

No.	Training objectives	Training scope
2	To acquaint the forest service with early detection system in a country they represent to be able to deploy it in practice and to follow detection procedures.	Scheme and description of the national early detection system. Specific detection procedure for forest service from the ground and/or from the air.
3	To acquaint UAV operators with early detection system in a country they represent to be able to support it in practice and to follow detection procedures.	Scheme and description of national early detection system. Specific operational procedure to support the system by UAV operators from the air.
4	To acquaint public administration bodies with the early detection system in a country they represent to be able to use/manage it in practice and to follow detection procedures.	Scheme and description of national early detection system. Specific operational procedure to use/manage the system by public administration.
5	To acquaint wildfire responders with the system of transmitting information about the occurring hazard.	Scheme and description of the system for communicating information on the occurring hazard.
6	To prepare wildfire responders to effective crisis communication procedures (formal communication between the responders).	Crisis communication procedures (formal communication between the responders) during wildfire (especially during first stage of the hazard development).
7	To prepare wildfire responders (especially decision makers) for effective risk communication procedures (formal communication with the public).	Risk communication procedures (formal communication with the public) during wildfire (especially during first stage of the hazard development).
8	To familiarise wildfire responders with specification of early detection of hazard.	Physical, chemical and biological issues determining wildfire and its detection (including weather conditions, fire scene conditions).

No.	Training objectives	Training scope
9	To familiarise wildfire responders with the need and solutions (technical ones and procedural ones) to confirm wildfire detection positives (due to a risk of 'false-positives').	Mechanism of generating 'false-positives' in early detection systems and operational ways to verify them.
10	Practical exercise in the use of detection tools under field conditions by fire responders (especially UAV operators, fire services and forest services).	Manual and practical issues related to the deployment of particular detection tools by UAV operators, fire services and forest services).
11	To acquaint wildfire responders with early detection system <<Fire detect>> to be able to use it in practice and to follow detection procedures.	The video detection system <<OiB-Fire Detect/Stribor>> is covering the coastal part of Croatia. The signal and management of the cameras is connected to the firefighting alarm centres. The system warns the operator by providing the appropriate signal or colour of possible ignition of fires and specific detection procedure for firefighting operators in fire-fighting alarm centres. The education includes the use of a fire-propagator (system for predicting the spreading of wildland fires). The education is provided by the public company "Odašiljači i veze-transmitters and connections" and the University in Split – Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture. A tower-based fire detection system in Poland.

No.	Training objectives	Training scope
12	To acquaint wildfire responders with the SILVANUS dashboard/ UI composed of selected tools and services for early detection of wildfires. NOTE: UI training objectives can be applied also to other phases of wildfire response (i.e., phases 2–6), depending on the tools and services integrated in the SILVANUS UI.	Usage, modes and tools incorporated into the SILVANUS dashboard, capabilities for configuration and customization of views, description of UI menu and notifications, management of information provided via the dashboard. NOTE: UI training scope can be applied also to other phases of wildfire response (i.e., phases 2–6), depending on the tools and services integrated in the SILVANUS UI.

Source: own study based on (SILVANUS D3.2, 2023)

Training should ensure that wildfire responders and wildfire managers are familiarised with early detection systems that operate in relation to wildfire risk. This applies to both organisational systems (that provide inter-agency and multi-entity risk communication and crisis communication) and technical systems (in the meaning of particular technology solutions). They could be country-specific and some of them may be EU-level solutions. Both cases should be taken into consideration to prepare trainees for operation in a familiar common detection framework when necessary. It is crucial also for wildfire responders from abroad (for example when dispatching rescUE resources or getting support from neighbouring countries). The main idea is to ensure that a trainee can be sure that hazard-related information is actual, complete and reflect real safety and security determinants.

Table 8 presents results of the information gathering process related to training objectives and scope regarding to immediate dispatch of wildfire responders.

Table 8. Training objectives and scope for immediate dispatch of wildfire responders

No.	Training objectives	Training scope
1	To present organizational dispatch system for wildfire responders.	Organisational structure, objectives and dispatch mechanisms for wildfire responders.
2	To present technical dispatch system for wildfire responders and the use of its chosen functionalities.	General specification and functionalities of the dispatch system.
3	To familiarize with the information exchange between wildfire responders regarding immediate dispatch to action.	Structure of the information exchange (including reliable information sources, information from citizens and decision makers).
4	To present information necessary to make a decision about the dispatch of wildfire responders to action.	Information to be collected to be able to make a decision about the dispatch of wildfire responders to action.
5	To acquaint wildfire responders with the system of optimising the selection of rescue forces' potential.	Description of the system for selecting the potential of rescue units to extinguish a forest fire.
6	To acquaint wildfire responders with the minimum necessary equipment including vehicles, equipment and extinguishing agents for extinguishing forest fires.	Description of a selection system for equipment with vehicles, equipment and extinguishing agents for extinguishing forest fires.

No.	Training objectives	Training scope
7	To present alternatives for “typical” wildfire responders (fire service, forest service) to be used in case of emergency.	Analysis of alternatives for “typical” wildfire responders (fire service, forest service) to be used in case of an emergency (e.g., when the responders may prove to be inadequate or are too far away from the wildfire scene), including UAV operators, NGOs, entrepreneurs etc.
8	To connect immediate dispatch of wildfire responders with crisis communication mechanisms in public administration bodies.	Crisis communication mechanisms in public administration bodies respecting immediate dispatch of wildfire responders.
9	To acquaint wildfire responders with the fire management system <<Upravljanje vatrogasnim intervencijama - Fire Management System>> to be able to deploy it in practice and to follow alarm, surveillance, geoinformation and recording procedures.	The fire management system <<Upravljanje vatrogasnim intervencijama – Fire Management System>> is free on dispatch to all firefighting units in Croatia. It is a web-application connected with the GIS–system <<GISCLOUD>>. The system defines procedures for fire-fighting operators in firefighting alarm centres. The education comprises the use of the alarm system, the fire management system, the surveillance system (vehicles and fire-fighters) and the GIS system.

Source: own study based on (SILVANUS D3.2, 2023)

The need of becoming familiarised with organisational and technical solutions in the training for wildfire response is noticeable also when talking about immediate dispatch of wildfire responders. As a rule, the dispatch must be immediate and apply to resources that are quantitatively and qualitatively accurate to handle a disaster (wildfire and relevant secondary threats). Apart from local resources, external supporters should be taken into account (for example firefighting troops from abroad). This determines processes of information exchange and gives rise to the need of resource optimisation. Training should take into account that resources are limited. They must be distributed and used rationally. Operational retreats should also be provided. Special attention should be paid to entities that may support “classical” wildfire responders (such as fire services and forest services) during their operations and state operational alternatives and equivalents. Case studies from different countries may provide inspirations on how to improve the dispatch of wildfire responders in other places.

Table 9 presents results of the information collecting process regarding training objectives and scope regarding to effective delivery of necessary resources to the wildfire scene.

Table 9. Training objectives and scope for effective delivery of resources to the wildfire scene

No.	Objectives of the training	Scope of the training
1	To acquaint wildfire responders with the system of fire commuting.	Description of fire roads organization system in forest areas. Marking and signage of access roads.
2	To present IT solutions allowing the visualisation of the road network to allow delivery of necessary resources to the wildfire scene.	IT solutions allowing the visualisation of the road network for the needs of getting of the resources to the wildfire scene (e.g. GIS).
3	To exercise the practical use of mobile IT solutions allowing the visualisation of the road network to allow the delivery of resources to the wildfire scene.	Mobile IT solutions allowing the visualisation of the road network to allow delivering the resources to the wildfire scene (e.g. GIS).
4	To teach how to optimise arrival routes to the wildfire scene from the perspective of ground resources (e.g. fire engines).	Use of maps (paper ones and GIS) to optimise arrival routes to the wildfire scene from the perspective of ground resources.
5	To teach how to optimise arrival routes to the wildfire scene from the perspective of air resources (e.g., UAVs, firefighting planes).	Use of maps (paper ones and GIS) to optimise arrival routes to the wildfire scene from the perspective of air resources.

No.	Objectives of the training	Scope of the training
6	To demonstrate how ground resources can be supported by airborne resources to effectively reach the fire scene.	Supporting procedures and good practices in the common use of maps (paper ones and GIS).
7	To become familiarised with practical opportunities to capitalise on citizen involvement (e.g., social media) to increase the effectiveness of getting to the wildfire scene.	Social media tools allowing the identification of ‘bottle necks’, communication impediments and alternative arrival routes to the wildfire scene.
8	To acquaint wildfire responders with the water supply organisation system for firefighting purposes in forests.	Description of the water supply organization system in forest areas. Setting out water intake points
9	To acquaint wildfire responders with the forest infrastructure organisation system.	Description of the organization of forest infrastructure related to fire protection. Requirements. Location of the infrastructure.
10	To acquaint wildfire responders with the fire management system <<Upravljanje vatrogasnim intervencijama – Fire Management System>> to be able to use it in practice and to follow alarm, surveillance, geoinformation and recording procedures.	The fire management system <<Upravljanje vatrogasnim intervencijama – Fire Management System>> is available free-of-charge dispatch to all fire-fighting units in Croatia. It is a web-application connected with the GIS –system <<GISCLOUD>>. The system defines procedures for firefighting operators in firefighting alarm centres. The training comprises the use of the alarm system, the fire management system, the surveillance system (vehicles and fire-fighters) and the GIS system. The training lasts 8 hours for alarm and surveillance system and 16 hours for GIS-system and is delivered by Croatian firefighters.

Source: own work based on (SILVANUS D3.2, 2023)

As a rule, delivering resources to a wildfire scene is the responsibility of field commanders who dispatch those resources to action. However, common access to different information sources (for example GIS) may be inspiring for dispatchers, action staff members, emergency management teams, disaster management teams, crisis management teams and other entities to support commanders when they choose the optimal arrival way in the given circumstances and conditions. This is the next valuable direction for training of wildfire response. IT dashboards, GIS, satellite tools, and UAVs may be helpful to express supporting potential in this case. However, the woods are challenging from the viewpoint of terrain conditions. Consequently, trainees should be additionally prepared to handle things on their own (without technology support) when approaching action on the basis of classical topographical techniques and skills (for example on “how to read the woods”).

Table 10 presents results of the process of collecting information about training objectives and scope regarding to comprehensive recognition of hazard situation (from ground and air).

Table 10. Training objectives and scope for comprehensive reconnaissance of hazard situation (from the ground and the air)

No.	Training objectives	Training scope
1	Becoming familiarised with organisation of the reconnaissance system.	Description of the reconnaissance system organisation.
2	Describing and practicing the reconnaissance system by ground patrols.	Description of the reconnaissance system by ground patrols. Practical reconnaissance by ground patrols.
3	Describing and practicing the reconnaissance system by aerial patrols.	Description of the reconnaissance system by aerial patrols. Practical reconnaissance by aerial patrols.
4	Describing and practicing the communication system among ground patrols.	Description of the communication system among ground patrols. Its deployment in field conditions.
5	Describing and practicing the communication system among aerial patrols.	Description of the communication system among aerial patrols. Its deployment in field conditions.

No.	Training objectives	Training scope
6	Describing and practicing the integrated communication system (among ground patrols and aerial patrols).	Description of integrated communication system (among ground patrols and aerial patrols). Its deployment in field conditions.
7	Acquainting wildfire responders with supporting the reconnaissance systems by observation points.	Supporting mechanisms for reconnaissance systems with the use of observation points.
8	Deploying modern technologies for effective communication with commander during the reconnaissance.	Exercises involving modern technologies for effective communication with the commander during reconnaissance in field conditions.
9	Deploying alternative means for effective communication with commander during the reconnaissance.	Exercises with alternative solutions for effective communication with the commander during reconnaissance in field conditions.
10	Familiarisation with reliable ways to check the information correctness.	Ways of checking information correctness basing on cooperation with other wildfire responders and citizens.
11	Exercising the use of technological tools for the reconnaissance.	Practical use of technological tools for reconnaissance (e.g., UAVs, thermovision, GIS, visual cameras, satellite images).

Source: own work based on (SILVANUS D3.2, 2023)

Comprehensive investigation of the hazard situation (from the ground and the air) should be carried out by effective reconnaissance activities. This requires the trainees to become familiarised with reconnaissance organisation, means and manners, as well as preparing them to handle reconnaissance in conditions of communication limits and lack of information. A broad range of technological solutions may be adopted for this wildfire response phase. They should be equivalent and provide the same situational picture. Furthermore, the trainee must be ready to verify the existing information and collect additional data by improvised measures, also in cooperation with other wildfire responders. All these issues must ensure a situational picture, which would fully reflect real wildfire conditions.

Table 11 presents results of the information gathering process regarding training objectives and scope regarding to firefighting tactics.

Table 11. Training objectives and scope for firefighting tactics

No.	Training objectives	Training scope
1	To acquaint with methods of locating ground resources (mainly fire engines and water support lines).	Methods of locating ground resources (mainly fire engines and water support lines) taking into consideration maps, transport network and sources of water supply.
2	To acquaint with ways of locating aerial resources (mainly UAVs).	Ways of locating aerial resources (mainly AUVs) taken into consideration maps, transport network and area to analyse from air.
3	To familiarise with the firefighting area organisation.	Description of the cooperation system between the fire brigade, local administration and forest service. Operational areas, optimal use of resources. Command structure. Coordination of firefighting activities.
4	To familiarise with the operational system of aircraft extinguishing.	Description of the aircraft administration system. Principles for cooperation during a firefighting operation using aircraft. (Landing field – technical facilities, water supply. Communication with aircraft). Operational use of firefighting aircraft. Coordination of aviation activities.
5	To acquaint with the operating system of using UAVs.	Description of the drone use system during firefighting actions.

No.	Training objectives	Training scope
6	To demonstrate and exercise basic structures of hose lines for extinguishing attack to the wildfire.	Basic structures of hose lines for a wildfire extinguishing attack, regarding different (qualitatively and/or quantitatively) ground resources.
7	To demonstrate and exercise basic structures of hose lines for extinguishing defence from the wildfire.	Basic structures of hose lines for a wildfire extinguishing defence, regarding different (qualitatively and/or quantitatively) ground resources.
8	To familiarise with water supply tactics in different ground conditions.	Multiple water supply tactics in different ground conditions with different resources accessible (e.g., fire engines, water main lines, motor pumps, water tanks).
9	Extinguishing and landing craft during forest fires: use of tactics, equipment and coordination with other organisations.	For professional firefighters: to become acquainted with the basic wildland suppression tactics and equipment. Direct and indirect attack on a fire, depending on the fire line intensity.
10	Extinguishing wildfires and helicopter transport.	For volunteer firefighters: to become acquainted with basic wildland suppression tactics and equipment and with helicopter transport.
11	To gather information about fire characteristics and behaviour to formulate the tactics of the response.	Information concerning fire line intensity, rate of spread, spotting activity, distance.

Source: own elaboration based on (SILVANUS D3.2, 2023)

Firefighting tactics is the essential issue when talking about wildfire response. All previous phases are to prepare and establish foundations for the response. Each trainee needs to be familiar with elements of the tactics regarding the proper location of resources (to reduce operational risks), manners for organising the firefighting scene, hose-line structures to provide extinguishing action in attack or in defence, water supply, and logistics in the wooded areas. Special attention should be placed on effective cooperation between ground troops and aerial vehicles to maximise their synergistic effect in extinguishing action. It is also necessary to develop the skill of improvising and adjusting the tactics to the dynamic wildfire environment and conditions. In other words, training should deliver not only information puzzles but also ready-to-implement and verified methods allowing their incorporation into effective firefighting action.

Table 12 presents results of the information gathering process regarding training objectives and scope for cooperation between firefighting entities.

Table 12. Training objectives and scope for cooperation between firefighting entities

No.	Training objectives	Training scope
1	To acquaint wildfire responders with a cooperation system for firefighting entities.	Description of the firefighting coordination system. Cooperating institutions.
2	To present alternatives for ‘typical’ wildfire responders (fire service, forest service) to be used in case of an emergency.	Analysis of alternatives for ‘classical’ wildfire responders (fire service, forest service) to be adopted in case of an emergency (e.g., where the responders may turn out inadequate or too far away from the wildfire scene), considering UAV operators, NGOs, entrepreneurs etc.
3	To prepare wildfire responders (especially decision makers) for effective risk communication procedures (formal communication with the public).	Risk communication procedures (formal communication with the public) during wildfires (especially during the first stage of hazard development).
4	To acquaint wildfire responders with the information transmitting system about hazard development (e.g., cascading effect).	Scheme and description of the system for communicating the development of the threat (e.g., cascading effect).

No.	Training objectives	Training scope
5	To prepare wildfire responders for effective crisis communication procedures (formal communication between the responders).	Crisis communication procedures (formal communication between the responders) during a wildfire (especially during the first stage and successive ones of hazard development).
6	To demonstrate how to use technology and equipment to optimise the use of human resources on a wildfire scene.	Alternatives for the use of human resources (e.g., firefighters, aerial patrols) considering UAVs, stationary extinguishing points, fire barriers etc.
7	To prepare wildfire responders to conduct their activities with safety procedures in mind.	Occupational health and safety procedures for wildfire responders and their practical implementation during large scale field exercises.
8	To teach how to identify mutual operational needs among firefighting actors.	Mutual operational needs among firefighting actors, paying special attention to particular kinds of entities (fire service, forest service, aircraft pilots and UAVs operators) as well as particular phases of wildfire response (early detection and communication of the hazard, immediate dispatch of wildfire responders, effective delivery of resources to the wildfire scene, comprehensive reconnaissance of the hazard situation (from the ground and the air), firefighting tactics, cooperation between firefighting actors).
9	Air-force guidance: principles of guidance for air-forces.	For firefighting commanders: education on principles and methods of communication with firefighting air forces. This training lasts 40 hours and is delivered by HVZ.

No.	Training objectives	Training scope
10	To learn how to cooperate with firefighters from other countries (in case of receiving international assistance through Union Civil Protection Mechanism – UCPM, on a bilateral basis etc.) and to provide a high level of Host Nation Support (based on EU Host Nation Support Guidelines) to the incoming modules.	Participation in international missions, exercises (i.e., EU MODEX), exchange of expert programmes (i.e., pre-positioning of firefighters' programme of UCPM) and UCPM training courses to enhance interoperability (to speak the same language) in civil protection operations.
11	To gather and share information about fire characteristics and behaviour to allow the formulation of the response tactics .	Information concerning the fire line intensity, rate of spread, spotting activity, distance as well as particular tactics of entities involved in a wildfire response.

Source: own work based on (SILVANUS D3.2, 2023)

Cooperation allows maximising the synergy effect of wildfire response. On the other hand, fire service and forest service may prove to be insufficient to face the hazard under consideration in the conditions of a disaster and/or co-existing hazards. Trainees need to be familiar with cooperation possibilities, standards and requirements to plan and conduct common efforts in an effective way. Thus, training should be oriented at a system approach on cooperation, initiating alternative resources and conducting multi-entity communication (crisis communication and risk communication). This also applies to safety procedures and the use of new technologies as not all entities may be preliminarily and equally prepared for it as "classical" wildfire responders.

As far as training objectives are concerned, their analysis allows the development of a training scope or its elements. They need to be tailored to current training needs and expectations. Moreover, some of the research results seem to cross-cut two and more phases of wildfire response. They include, for example, shaping situational awareness, crisis communication and the use of new technologies. This means that preparation and pre-planning activities for wildfire response in the form of a training can be optimised, apply to one or more response phases and allow the use of multiple technologies. The training organiser can match these elements to ensure effective training curricula and training protocols.

3.4. Training forms and methods

Training forms and methods mean specific ways for achieving all training objectives and covering the entire training scope. At the highest level of generality, they should ensure effective transfer of knowledge and development of skills during a training course. In addition, they need to be formulated in detail to identify specific methodological directions for the training. Training forms represent a general educational framework for the organisation of training. In turn training methods are specific ways of organising them. Some of the methods are specific for relevant forms. Special attention should be placed on high-effectiveness forms and methods to maximise the educational effect in the given time of a training (Gromek, 2021).

Training forms and methods were specified in the second survey sent to all partners under Task 3.3 in the SILVANUS project, and discussed during the Second International Scientific Seminar on Preparation and Pre-Planning Activities for Wildfire Response “Training Forms and Methods” (29 September 2022). The main objective of the survey method was to identify training forms and methods for fire services, forest services, UAV operators and public administration representatives involved in wildfire response. Responders were informed that the forms and methods should have allowed to reflect operations to be carried out during first period after wildfire outbreak, ascribing into early detection and communication of the hazard, immediate dispatch of wildfire responders, comprehensive reconnaissance of the hazard situation (from the ground and the air), effective delivery of resources to the wildfire scene, firefighting tactics (including ensuring continuous access to water) and cooperation between firefighting actors. In addition, particular attention should be paid to the use of modern technologies (including AR/VR) as well as best educational and training solutions. The training should reflect the specification (scope, technologies, stakeholders involved, detail issues etc.) of wildfire-determined case studies. It should also be open for an entire spectrum of multiple training forms and methods, such as lecture, discussion, presentation, problem solving method, table top exercises, field exercises, field demonstrations, demonstrations with equipment, computer simulation, AR/VR simulation, work with handbook, brainstorming, decision training, multimedia decision training etc.

Table 13 presents results of the information gathering process related to training forms and methods regarding early detection and communication of the hazard.

Table 13. Training forms and methods for early detection and communication of the hazard

No.	Training form and/or method	Objective of the form and/or method
1	Lecture	1. To increase knowledge on the physical landscape (orography, vegetation, biodiversity, human occupation). 2. To present local early detection systems and their basic functionalities. 3. To provide operational guidelines on how to address media, citizens, firefighters, municipalities, authorities, etc. 4. To get acquainted with various systems. 5. To present functionalities of national early detection systems in practice and practical handling with the system. 6. To acquaint with the information transmitting system related to potential hazards to responders, public (including crisis communication).
2	Presentation	
3	Talk	
4	Work with printed materials	
5	Simulation (including computer simulation)	
6	E-learning system	
7	Manual training in the operation of early detection systems (e.g., ‘Fire detect’ and ‘Fire propagator Stribor’ – 5-day long training).	
8	On-site observation	

Source: own work based on (SILVANUS D3.2, 2023)

Training forms and methods used to prepare trainees for early detection and communication of the hazard need to ensure becoming familiarised with the general situational picture before a hazard occurs, and practical operational issues related to early warning systems. As a rule, the warning may be considered early when the system operator notifies a hazard as soon as it materialises. Practical abilities are crucial in this case. Classical training methods (lecture, discussion, talk) should be used to present and analyse the situational picture and the system functionalities. Nevertheless, particular attention needs to be placed on simulations, manual trainings and observations to develop and consolidate individual practical skills. The e-leaning formula may be deployed as a supplement method – never as the only one.

Table 14 presents results of the information gathering process with regard to training forms and methods for immediate dispatchof wildfire responders.

Table 14. Training forms and methods for immediate dispatch of wildfire responders

No.	Training form and/or method	Objective of the form and/or method use
1	Lecture	1. To provide the fastest and the most efficient deployment of firefighting entities, namely by identifying safe routes, water reservoirs, fire shelters, etc. 2. To present functionalities of national alarm, surveillance (tracking) and GIS system and practical handling of the system. 3. To use the system on its own. 4. To present the system of rescuers' dispatch. 5. To acquaint with the local cooperation system between forest managers and fire services during forest fires. 6. To present new technological solutions to enable the most effective dispatch of rescuers to a fire (as well as tracking rescuers, GIS).
2	Presentation	
3	Talk	
4	Work with printed materials	
5	Simulation (including computer simulation)	
6	Classical problem method	
7	Case study	
8	Table top exercises	
9	Decision training	
10	Practical exercise	
11	E-learning system	

Source: own work based on (SILVANUS D3.2, 2023)

Immediate dispatch of wildfire responders requires the use exercise-related forms and methods to show how to optimise resources of wildfire responders to be dispatched, and how to communicate the results of optimisation to the responders. Training should also allow establishing appropriate conditions to allow identifying safe routes, water reservoirs, fire shelters and other elements that determine the dispatch to assure that it proceeds in an optimal way. Case studies, table top exercises, decision trainings and practical exercises are particularly valuable to examine different dispatch conditions and circumstances and to discuss them. Again, the e-leaning formula cannot be the only one in terms of training forms and methods. It may be quite useful to establish a training background and to create a platform for training materials.

Table 15 presents results of the information gathering process training forms and methods regarding to effective getting of the resources to the wildfire scene.

Table 15. Training forms and methods for effective delivery of resources to the wildfire scene

No.	Training form and/or method	Objective of the form and/or method use
1	Lecture	1. To increase knowledge on road networks and access to the danger zone. 2. To increase knowledge on access to water sources. 3. To increase knowledge on human occupation. 4. To develop methodologies that enable biodiversity and wildlife protection. 5. To present functionalities of national alarm, surveillance (tracking) and GIS system and practical handling of the system. 6. To acquaint with new technologies enabling efficient and fast delivery of resources to the wildlife scene 7. To acquire knowledge about forest infrastructure, access to water, communication between rescuers.
2	Presentation	
3	Talk	
4	Simulation (including computer simulation)	
5	Classical problem method	
6	Case study	
7	Table top exercises	
8	Decision training	
9	E-learning system	
10	Use of ‘Fire propagator’ – the fire management system unites activities related to the dispatch of firefighting resources, road network, access to water, infrastructure and wildfire-spreading	

Source: own work based on (SILVANUS D3.2, 2023)

Effective delivery of resources to the wildfire scene requires preparing drivers, commanders and dispatchers to optimally plan arrival routes. Thus, essential knowledge about terrain conditions, routes, water reservoirs, potential fire defence lines, and biodiversity is needed. It may be transferred by classical teaching methods (for example lecture, presentation, talk) as well as by providing high-effectiveness formulas (table top exercises, decision training, etc.). When a fire service has its own dispatch system, it is valuable to incorporate it to the training process and adjust to wildfire scenarios. Decision-making problems should be considered as well. They could cover arrival problems that are typical (to appoint the optimal arrival route) and/or untypical (to urgently modify arrival route due to hazard development) for wildfire responders.

Table 16 presents results of the information gathering process about training forms and methods regarding comprehensive recognition of hazard situation (from the ground and the air).

Table 16. Training forms and methods for comprehensive identification of the hazard situation (from the ground and the air)

No.	Training form and/or method	Objective of the form and/or method use
1	Lecture	1. To increase knowledge and proficiency in tools and procedures. 2. To present modern technological solutions (hardware, software, satellite techniques) for ground and air reconnaissance. 3. To check organisational procedures in practice.
2	Presentation	
3	Talk	
4	Discussion	
5	Simulation (including computer simulation)	
6	Classical problem method	
7	Case study	
8	Wildfire history study	
9	Practical exercises	
10	Field exercises	
11	E-learning system	

Source: own work based on (SILVANUS D3.2, 2023)

Comprehensive identification of hazard situation (from the ground and the air) is intended to define the situational picture necessary to formulate firefighting tactics and shape effective coordination between wildfire responders. For this reason training should ensure a wide spectrum of forms and methods to develop reconnaissance and analytical skills, with strong support of multiple sources of information (sensors, detectors, decision support systems, UAVs, robots, communication systems, etc.). The good practice is to start training with the use of classical teaching methods (lecture, talk, presentation) to prepare for the essential part of the training process. E-learning may be used to support this process. essential fundamental part should consist of practical exercises and/or field exercises to develop specific skills and test new knowledge in quasi-real or real conditions in the woods.

Table 17 presents results of the information gathering process of about training forms and methods regarding firefighting tactics.

Table 17. Training forms and methods for firefighting tactics

No.	Training form and/or method	Objective of the form and/or method use
1	Lecture	1. To expand knowledge on first stage tactics formulation, division of the hazard scene into operational areas, optimal use of resources, reflecting forest environment. 2. To get acquainted with wildland suppression tactics and equipment. 3. To demonstrate and use practical of wildland firefighting equipment in practice. 4. To make jumps from helicopter in difficult conditions. 5. To comply with health and safety rules appropriate to the field conditions.
2	Presentation	
3	Talk	
4	Discussion	
5	Debriefing	
6	Classical problem method	
7	Case study	
8	Table top exercises	
9	Decision training	
10	Practical exercises	
11	Field exercises	
12	E-learning system	
13	Education for << Extinguishing and landing (storming) on wildlife fire sites >>, 3.5 day education and training for professional firefighters (30 hours), 2.5 day education for volunteer firefighters (20 hours)	

Source: own elaboration based on (SILVANUS D3.2, 2023)

Firefighting is the core element in wildfire response. Conditions prevailing in the forest and the specific nature of the wildfire phenomenon significantly regulate expectations of specific training. Effective practice is required to prepare wild-fire responders to operating directly to put out a fire. The first part of a training can address theoretical information, standards and good practices for firefighting tactics, with special place for case studies and discussion on practical problems and making complex tactical decisions. The main training part, however, needs to be organised in the formula of exercise. It is important to be aware about the duration and practical constrains of particular tactical activities. Training firefighting tactics generate also possibilities for the use of engines and equipment of wildfire responders to try them out in quasi-real or real conditions of response in the woods.

Table 18 presents results of the information gathering process concerning training forms and methods regarding cooperation between entities fighting the fire.

Table 18. Training forms and methods for cooperation between firefighting entities

<table>
<tr><th>No.</th><th>Training form and/or method</th><th>Objective of the form and/or method use</th></tr>
<tr><td>1</td><td>Presentation</td><td rowspan="14">1. To promote acquaintance with firefighting procedures.
2. To promote communication and joint operational effectiveness.
3. To get acquainted with wildland suppression tactics and guidance for aircraft.
4. To present wildland firefighting tactics for air forces (Canadair, air tractor and helicopter).
5. To organise practical exercise using aerial means.
6. To organise practical exercise on the training ground using aerial means (airplanes, UAV).
7. Participation in the UCPM training Programme, EU MODEX exercises, Exchange of Experts Programme.</td></tr>
<tr><td>2</td><td>Debriefing</td></tr>
<tr><td>3</td><td>Talk</td></tr>
<tr><td>4</td><td>Discussion</td></tr>
<tr><td>5</td><td>Classical problem method</td></tr>
<tr><td>6</td><td>Case study</td></tr>
<tr><td>7</td><td>Brainstorming</td></tr>
<tr><td>8</td><td>Didactic games</td></tr>
<tr><td>9</td><td>Table top exercises</td></tr>
<tr><td>10</td><td>Decision training</td></tr>
<tr><td>11</td><td>Practical exercises</td></tr>
<tr><td>12</td><td>Field exercises</td></tr>
<tr><td>13</td><td>E-learning system</td></tr>
<tr><td>14</td><td>Education for << Air-force guidance >> (4-day education and training for leaders in firefighting intervention).</td></tr>
</table>

Source: own work based on (SILVANUS D3.2, 2023)

Cooperation between firefighting actors is challenging from the viewpoint of training. It requires tailoring training forms and methods to the needs of different users, and do it in an integrated way. Nonetheless, in this case there is a broad valid catalogue of training forms and methods. The simple ones (presentation, talk, discussion) should be adopted to create a theoretical background for co-operation and to establish the cooperation structure (making sure that every entity is aware of its tasks and duties). The more complex forms and methods are valuable to develop cooperation skills via solving complex decision-making problems and undertaking common efforts to face a wildfire. Field exercises are very welcome in this case. The Union Civil Protection Mechanism is a good example on how to organise such training in a way that allows maximising the educational effect at an international scale.

In addition, it is also necessary to adjust training duration to individual forms and methods. From the practical point of view and to ensure flexibility for training organisers, it is suggested that the following reference durations be taken into consideration to achieve relevant aims:

1) 2–3 hours: presentation of early warning, data collection and communication solutions – for example to expand knowledge of the physical landscape (orography, vegetation, biodiversity, human occupation).
2) 6–8 hours: – familiarization with procedures, good practices, technological solutions, etc. – for example to present modern technological solutions (hardware, software, satellite techniques) for ground and air reconnaissance.
3) 12 hours: organization of field exercises for practical use of new technologies, response strategies and cooperation issues – for example to organise practical exercise on the training ground using aerial means (airplanes, UAV).
4) 20 hours: comprehensive training for voluntary responders responsible for providing support at the wildfire scene (e.g. volunteer firefighters) – for example to get acquainted with basic wildland suppression tactics and equipment and transport with helicopter.
5) 30 hours: comprehensive training for professional responders assigned with commanding at the wildfire scene (e.g. professional forest services, professional firefighters) – for example to get acquainted with basic wildland suppression tactics and equipment, direct and indirect fire attack, depending on the fire line intensity.

Training should be organised by institutions and organizations experienced in high-effective education of fire professionals (for example forest fire education centres, firefighting units, universities – including organizers and consortia under the umbrella of the European Union and the United Nations) with strong support of technology providers (relevant for equipment used during the trainings).

Training target groups are basically entities that respond to wildfire directly and indirectly. Direct response to a wildfire refers to firefighting units of forest services, voluntary firefighters, professional firefighters, soldiers, etc. Indirect response to a wildfire applies to:

a) UAVs operators and UGVs operators (for example to carry out reconnaissance from the air and the ground),
b) public administration (for example to coordinate the entire domain of response operation),
c) police (for example to secure access roads and provide support in evacuation),
d) critical infrastructure operators (to become better prepared for protection of the infrastructure against wildfire and its manifestations),
e) forest owners (to gain information about wildfire protection means and methods),
f) technology providers (to evaluate their solutions and open up to operational needs and expectations of wildfire management),
g) citizens and their groups involved in the response (for example owners of plows and other heavy equipment to make ground defence lines).

3.5. Training materials

Training materials comprise all information sources useful in the transfer of knowledge and development of skills related to training for wildfire response. The materials should be adjusted to specific training forms and methods, and need to cover as much of the training scope as possible. To make them operational, training materials should be shared with training attendees before, during and after the training. The e-learning platform is considered to be a valuable form of materials sharing. Furthermore, the content of such materials needs to be tailored to cognitive abilities of trainees to ensure that they are able to compile all necessary information immediately and effectively.

Training forms and methods were specified within the second survey sent to all partners under Task 3.3 in the SILVANUS project, and discussed during the

Third International Scientific Seminar on Preparation and Pre-Planning Activities for Wildfire Response "Training Materials" (15 December 2022). The main objective of the survey method was to identify and discuss training materials for the needs of fire services, forest services, UAV operators and public administration representatives involved in wildfire response. Responders were informed that the materials should consider operations to be carried out during the first period after wildfire outbreak, covered by early detection and communication of the hazard, immediate dispatch of wildfire responders, comprehensive recognition of hazard situation (from ground and air), effective getting of the resources to the wildfire scene, firefighting tactics (including ensuring continuous access to water) and cooperation between entities fighting the fire. Special attention should have been paid to correspondence with modern technologies, high quality content, reflecting of state-of-the-art as well as best educational and training solutions as well as on entire spectrum of multiple training materials (i.a.): books, handbooks, monographs, papers, articles, prevention programmes, operational procedures, cooperation standards, operational manuals (including these dedicated for use of special equipment), multimedia, presentations, leaflets, etc.

With regard to training materials on early detection and risk communication training, the following materials were presented and synthesised:

1) Slavkovikj, V., Verstockt, S., Van Hoecke, S., Van de Walle, R. (2014). 'Review of wildfire detection using social media', Fire Safety Journal, 68, pp. 109–118, https://doi.org/10.1016/j.firesaf.2014.05.021:
    a) Categorisation of wildfire risk management systems (to indicate the broad context).
    b) Current status of social media in wildfire risk management (to present general operational potential).
    c) Disaster management methods using social media information (examples of use).
    d) Crowdsourcing applications.
    e) Social media disaster management systems (a system for Social Media Alert and Response to Threats to Citizens, Tweeter, Global Disaster Alert and Coordination System GDACS).
    f) Social media data management – the sensing process (central coordination unit is required).
    g) Wildfire social sensor platform (IT solutions).
2) Jazebi, S., de León, F., Nelson, A. (2020). 'Review of Wildfire Management Techniques – Part I: Causes, Prevention, Detection, Suppression,

and Data Analytics', IEEE Transactions on Power Delivery, 35(1), pp. 430–439, doi: https://ieeexplore.ieee.org/document/8768218:

a) Main beneficiaries (wildfire prevention): power system engineers, electrical engineering academicians and suppliers of electrical apparatus.
b) Following issues important from the viewpoint of early detection: prediction and prevention means, detection methods, monitoring and surveillance techniques, suppression methods, allocation and mapping algorithms.
c) Damage and negative effects that a wildfire can cause to critical infrastructure.
d) It is valuable to present scenarios for multiple wildfire causes.

3) Bushnaq, O.M., Chaaban, A., Al-Naffouri, T.Y. (2021). 'The Role of UAV-IoT Networks in Future Wildfire Detection', IEEE Internet of Things Journal, 8 (23), p. 16984–16999, doi: https://ieeexplore.ieee.org/document/9424181:
   a) Presentation of multiple ways to detect wildfire (satellite imaging, remote camera-based sensing, unmanned aerial vehicles assisted Internet of Things (UAV-IoT) networks).
   b) Awareness of detection alternatives is crucial from the operational viewpoint (in terms of detection continuity as some detectors may be damaged or out of order).
   c) Limited system cost budgets determine final solutions implemented.
   d) Technical issues during the training need to be adjusted to the cognitive potential of trainees and practical training objectives.
4) Boulton, C.A., Shotton, H., Williams, H.T.P. (2016). 'Using Social Media to Detect and Locate Wildfires', AAAI Publications, Tenth International AAAI Conference on Web and Social Media, https://ojs.aaai.org/index.php/ICWSM/article/view/14850:
   a) Following social media investigated: Instagram, Twitter, MODIS, FPA.
   b) The more social media sources, the more possibilities to detect the hazard.
   c) Social media allow quicker hazard detection than classical warning calls to public services.
   d) New media means new detection possibilities – how to keep up?
5) Bouguettaya, A., Zarzour, H., Taberkit, A.M., Kechida, A. (2022). 'A review on early wildfire detection from unmanned aerial vehicles using deep learning-based computer vision algorithms", Signal Processing, 190, p. 108309, https://doi.org/10.1016/j.sigpro.2021.108309:

a) UAV technology and deep learning-based computer vision algorithms are connected to early wildfire detection.
b) UAV technology and deep learning-based computer vision algorithms connection requires a comprehensive system (data acquisition system, data processing, data transmission/receiving system, data processing on ground and concerned authorities).
c) UAVs of forest services, fire services and private owners.
d) Unification of operational standards or development of common standards are required.

6) OIV Fire Detect AI (Intelligent system for early fire detection) https://hvz.gov.hr/UserDocsImages/EU%20projekti/OIV%20Fire%20Detect%20AI.pdf:
a) Technological connection of video solutions, cloud computing and visualization tools.
b) National implementation level.
c) Involvement of international entities (for example European Civil Protection Mechanism units, firefighting units) requires ensuring access for those entities.

7) Barmpoutis, P., Papaioannou, P., Dimitropoulos, K., Grammalidis, N.A. (2020). 'Review on Early Forest Fire Detection Systems Using Optical Remote Sensing', Sensors, 20, p. 6442, https://doi.org/10.3390/s20226442:
a) Optical Remote Sensing technologies in early wildfire detection (flame and smoke detection).
b) Terrestrial, airborne and satellite-based systems are worth of being enumerated.
c) Awareness of strengths and weaknesses is crucial to allow the use of concrete solutions in practice.
d) Sensors: visible, infrared, multispectral.
e) Methods: machine learning, deep learning.
f) Training should be connected with solutions used by trainees.
g) Visualisation of the technology approach may be important to allow its understanding.

8) San-Miguel-Ayanz, J. et al., 'Comprehensive Monitoring of Wildfires in Europe: The European Forest Fire Information System (EFFIS), https://ec.europa.eu/environment/forests/pdf/InTech.pdf:
a) Monitoring may serve for early detection purposes on account of wildfire risk calculation.
b) Comprehensive risk-based monitoring requires a comprehensive approach to compile information (forest fire events, fire detection, burnt

area maps, land cover damage assessment, emission assessment, potential soil erosion estimates, vegetation regeneration, danger forecast).

c) The information must be at an acceptable level of quality.

d) The more countries involved, the more comprehensive information may be compiled.

e) An international level of the solutions is required.

9) Dampage, U., Bandaranayake, L., Wanasinghe, R. et al. (2022). 'Forest fire detection system using wireless sensor networks and machine learning', Scientific Reports, 12(46), https://doi.org/10.1038/s41598-021-03882-9:

a) Wireless sensor networks and machine learning as directions for development of wildfire detection.

b) Awareness about different (alternative) communication channels and communication tools is worth to be considered.

c) Wireless sensor networks require ensuring effective long-distance communication tools.

d) Field tests allow solutions to be tested in practice and help end-users learn about new technological solutions.

e) Machine learning support decision-making processes but does not take responsibility for safety or security of end-users.

10) Alkhatib, A.A.A. (2014). 'A Review on Forest Fire Detection Techniques', International Journal of Distributed Sensor Networks, 10(3), https://doi.org/10.1155/2014/597368:

a) Field trainings with detection tools may be used for their testing in operational conditions (it is important for technology providers with a potentially positive influence on sharing relevant tools for examination purposes).

b) A number of techniques are worth highlighting:

- fire weather forecasts and estimates of fuel and moisture,
- watch towers,
- optical smoke detection,
- lightning detectors used to detect the coordinates of the strike,
- infrared cameras/detectors,
- spotter planes,
- mobile/smart phone calls becoming increasingly common in early fire detection,

- education of house owners and tourists,
- satellite systems,
- digital cameras,
- spectrometers.

c) Individual techniques need to be chosen respecting training objectives and operational needs.

11) Wildland Fire Incident Management Field Guide (2013). National Wildfire Coordinating Group, https://www.nifc.gov/nicc/logistics/references/Wildland%20Fire%20Incident%20Management%20Field%20Guide.pdf:
    a) Early detection and communication are derivatives of wildland fire safety culture (awareness of the culture determinants may simplify enhancing the detection and communication effectiveness and is to be designed during the training processes).
    b) Access to media is crucial for early warning and mass communication of the hazard.
    c) Early warning and communication (scope of compiled information to be used to warn and to communicate the hazard) should be considered for needs of preliminary tactics and initial attack planning.
12) Guide to Wildland Fire Origin and Cause Determination (2016). National Wildfire Coordinating Group, https://www.nwcg.gov/sites/default/files/publications/pms412.pdf:
    a) Investigation of post-fire scene as a potential condition for warning about additional fire sources and a cascading effect of the hazard development.
    b) Development of on-side (field) ad hoc warning signals (warning flares, radio correspondence announcements, gesture messages, Morse code) and procedures may improve firefighters' safety and may determine the warning processes to match the hazard dynamism.

Training on immediate dispatch of wildfire responders can be supported by the use of the following materials:

1) National Wildfire Coordinating Group (NWCG) (1993). S-290: Intermediate wildland fire behavior. NFES 2378. National Interagency Fire Center. Boise, Idaho, https://training.nwcg.gov/dl/s290/s-290-student-workbook-all.pdf:
    a) Dispatch of particular equipment must reflect weather and topography.
    b) Dispatch destination (the danger zone or near-danger zone) must consider hazard development (including heat radiation, smoke, cascading

effect) and natural defence lines (roads, rivers, mountains, intersecting drainage, slope etc.).

c) In case of huge wildfires, marking places for resource concentration is a good operational practice.
d) The ability of calculating the fire zone is valuable at this stage of wildfire response.

2) National Wildfire Coordinating Group (NWCG) (2006). Fireline handbook, appendix B, fire behavior. NFES 2165. National Interagency Fire Center. Boise, Idaho, https://www.nwcg.gov/sites/default/files/products/appendixB.pdf:
   a) The dispatcher should correctly interpret information concerning fire behaviour.
   b) The ability of calculating the safety zone is valuable at this stage of wildfire response.
   c) Development of worksheets may facilitate the estimation of resource amounts and localization of the destination point (points, area) at this early stage of the response.
3) State plan for engagement of firefighting forces (only in Croatian) https://hvz.gov.hr/UserDocsImages/dokumenti/Program%20aktivnosti/Dr%C5%BCavni%20plan%20anga%C5%BEiranja%202022%20i%20O%20Plan.zip:
   a) Considering different wildfire locations allows the preparation of effective and immediate dispatch of wildfire responders.
   b) Crisis communication procedures should reflect operational communication procedures of wildfire responders (including radio code names, radio technical specification, etc.).
   c) The dispatcher must be familiar with wildfire response structures (entities' organizational structures and a general structure of the response).
   d) The immediate dispatch of wildfire responders should be based on specific information expressing the following: what?, who?, where?, how?, how many/how much?, why?, what for?.
4) Wollstein, K., O'Connor, C., Gear, J., Hoagland, R. (2022). 'Minimize the bad days: Wildland fire response and suppression success', Rangelands, 44(3), pp. 187–193, https://doi.org/10.1016/j.rala.2021.12.006:
   a) The immediate dispatch of wildfire responders should reflect preliminary tactics for the first attack on the hazard (basically this should be considered in operational procedures).

   b) The dispatcher should be familiar with local public-private partnerships that determine the overall wildfire response potential (for example plane owners, helicopter owners, off-road vehicles owners, UAV pilots).
   c) Knowledge about land ownerships is necessary to optimize response to a wildfire that affects both public and private forests (information about the danger zone, direct access to the danger zone, cooperation with forest owners and their forest services).
5) Martell, D.L. (2015). 'A Review of Recent Forest and Wildland Fire Management Decision Support Systems Research', Current Forestry Reports, 1, pp. 128–137, https://doi.org/10.1007/s40725-015-0011-y:
   a) Decision support systems may be used for automatic or semi-automatic (with human operation) dispatch of wildfire resources to the action scene.
   b) Decision support systems may optimize a demand for response resources arising from operational procedures.
   c) The immediate dispatch should serve for an initial attack on the fire in a timely and cost-effective manner.
   d) The dispatch must ascribe into strategic crisis (disaster) management priorities as necessary in the event of a wildfire, in many cases not only extinguishing actions but also organization of evacuation, preparation of infrastructure (including protection of critical infrastructure and ensuring its operability in wildfire conditions).
   e) Use of decision support systems requires awareness of their functional and technical issues in a scope reasonable from user point of view.
6) Calkin, D.E., Cohen, J.D., Finney, M.A., Thompson, M.P. (2013). 'How risk management can prevent future wildfire disasters in the wildland-urban interface, PNAS, 111(2), pp. 746–751, https://doi.org/10.1073/pnas.1315088111:
   a) Immediate dispatch of wildfire responders should reflect the specification of area in danger (wildland, urban, wildland-urban).
   b) The dispatch should take into account previous operational experience to optimize the use of wildfire response resources.
   c) Wildfire responders need to be directed to areas of optimized wildfire risk – this means a necessity of balancing between the fire risk (to fight the fire in areas where it poses the most serious challenge), operational risk (to ensure the response continuity) and work risk of the responders (to save life and health of the responders).

7) Wildland Fire Incident Management Field Guide, https://www.nifc.gov/nicc/logistics/ references/Wildland%20Fire%20Incident%20Management%20Field%20Guide.pdf:
   a) The responders designated for a specific hazard zone need to be equipped appropriately to personal safety requirements.
   b) The immediate dispatch of wildfire responders should also be connected to initiation of emergency (disaster, crisis) management team when a major wildfire occurs.
   c) A wildfire organizational point should be set up to collect information about the dispatch of all multiple wildfire responders (from different services and other entities).

Effective delivery of resources to the wildfire scene is a very specific topic in training. It may be delivered with the use of the following training materials:

1) Gkotsis, I., Petsioti, P., Eftychidis, G., Terzi, M., Kolios, P. (2021). 'Multiple Drone Platform for Emergency Response Missions' In: Akhgar, B., Kavallieros, D., Sdongos, E. (eds), Technology Development for Security Practitioners. Security Informatics and Law Enforcement. Springer, Cham. https://doi.org/10.1007/978-3-030-69460-9_29:
   a) Information about the location of resources delivery to the wildfire scene need to be accessible at the level of command and control unit.
   b) Transport means should ensure appropriate conditions for safe hauling of specialised equipment.
   c) Arrival roads should be treated as potential evacuation roads for wildfire responders in case of emergency (for example when unexpected development of a fire occurs increasing the risk for responders to an unacceptable level).
   d) There is a need of optimising arrival roads when they are simultaneously used as evacuation roads for citizens.
2) State plan for engagement of firefighting forces (only in Croatian), https://hvz.gov.hr/ UserDocsImages/dokumenti/Program%20aktivnosti/Dr%C5%BCavni%20plan%20anga%C5%BEiranja%202022%20i%20O%20Plan.zip:
   a) Considering different wildfire locations allows setting up effective and immediate arrival roads.
   b) Crisis communication processes may serve for the needs of arrival optimization (including multi-direction communication between different entities indicating desirable and undesirable directions and roads).

   c) Effective delivery of resources to the wildfire scene should base on specific information expressing the following: what?, who?, where?, how?, how many/how much?, why?, what for?.
3) NSW RFS Fire Trail Standards, https://www.rfs.nsw.gov.au/__data/assets/pdf_file/0009/69552/Fire-Trail-Standards-V1.1.pdf:
   a) It is necessary to become familiarised with fire trail standards (for example width, carrying capacity, turnarounds) to be able to choose proper routes in the forest to get effectively to the destination in the context of firefighting trucks and equipment conditions (size, transport means and manners, weight, etc.).
   b) The fire trail should be properly marked and the signage must be known to wildfire responders.
   c) Access to maps is crucial to analyse a network of fire trails in forest.
   d) Fire routes in forest may play a role of quasi-natural defence lines with influence on arrival and evacuation destinations and routes.
   e) Fire trucks have to be technologically adequate for forest conditions to be able to get to the destination point.
4) NSW Rural Fire Service Fire Trail Design, Construction and Maintenance Manual, https://www.rfs.nsw.gov.au/__data/assets/pdf_file/0009/97569/Fire-Trail-Design-Construction-and-Maintenance-Manual-FINAL_reducedsize.pdf:
   a) Trails are often related to drainage. Knowledge about this kind of connection may be useful in planning of defence lines in the forest with influence on arrival routes and directions.
   b) The driver should be aware of different ways of building a trail to be prepared to use it when arriving at the scene of a fire.
   c) The driver should be aware of the corridor width, formation width, longitudinal drainage and carriageway width as basic trail parameters crucial for effective getting to the fire scene.
5) Holuša, J., Koreň, M., Berčák, R., Resnerová, K., Trombik, J., Vaněk, J., Szczygieł, R., Chromek, I. (2021). 'A simple model indicates that there are sufficient water supply points for fighting forest fires in the Czech Republic', International Journal of Wildland Fire, 30, pp. 428–439, https://doi.org/10.1071/WF20103:
   a) The driver and the commander should know the location of water supply points. The points may be potential stops on the arrival roads to be used when necessary.

b) The location of water supply points should be taken into consideration when planning arrival routes and entire transport network for the needs of wildfire response.
c) Access to maps is crucial for analysing the location of water supply points and to carry out an operational analysis with their use.
d) Geospatial information systems are useful in marking arrival roads related to water supply points and in general.
e) Fire trucks must be prepared for the use of water supply points, when necessary, also during arrival to the fire scene.

6) Stergiadou, A. (2014). 'Prevention and suppression of forest-fires by using the road network and water tanks', Fresenius Environmental Bulletin, 23(11), pp. 2755–2761: https://www.researchgate.net/publication/279321072_Prevention_and_suppression_of_forest-fires_by_using_the_road_network_and_water_tanks:
a) Fire trucks must be prepared for using different water supply points when necessary, also during arrival to the fire scene (for example rainwater tanks, water ponds, fire hydrants, forest rivers, water basins).
b) The road network is often matched to places of water supply. This may consequently be used for optimization of arrival roads.
c) Access to maps is crucial to analyse the location of water supply points and to carry out an operational analysis with their use.
d) Geospatial information systems are useful in marking arrival roads regarding water supply points and in general.
e) Practical knowledge about water supply sources is necessary for their effective use during arrival to the wildfire scene.
f) Proper traffic management may lower traffic density on the arrival roads.

When considering comprehensive identification of the hazard situation (from the ground and the air), the following training materials are considered to be valuable sources of information for the training needs:

1) National Wildfire Coordinating Group (NWCG) (1981). S-390: Fire behavior. National Interagency Fire Center. Boise, Idaho, https://training.nwcg.gov/dl/s290/s-290-student-workbook-all.pdf:
a) Wildfire behaviour "(…) is shaped by its physical environment. Fire spread rates, fire intensity, and other characteristics of fire behaviour respond to the unique and ever-changing combination of the fire environmental components". The components are weather, topography and fuels.

b) The components are ever-changing so the reconnaissance process need to be ongoing and repeated.
c) Reconnaissance taking into account fire environmental components should consider topographic, fuels, basic weather processes, temperature and humidity relationships, atmospheric stability, wind systems and ways of observing the weather.
d) Wildfire responders should keep in mind conditions of extreme wildfire behaviour to be prepared to their identification and evaluation of firefighting tactics.
e) Comprehensive reconnaissance of hazard situation is to preliminarily point out the danger zone and the safety zone.

2) National Wildfire Coordinating Group (NWCG) (2004). Fireline handbook. NFES 0065. National Interagency Fire Center. Boise, Idaho, https://www.nwcg.gov/sites/default/files/products/appendixB.pdf:
a) Preparation for comprehensive reconnaissance of the hazard situation should take into account previous experiences and case studies to operationalize theoretical issues by demonstrating their practical dimension.
b) Tables are effective ready-to-use sources of information when recognizing the hazard situation (for example 'wildfire area estimations for point source fires as a function of wind speed').
c) Charts are also valuable in the reconnaissance processes (for example 'relation between flame height and a diameter at breast height').
d) There is a need of adjusting the fire behaviour theory to operational needs of wildfire responders (as not everything is crucial from the operational viewpoint).

3) Materials (manuals) of Air Forces of the Ministry of Defence (MoD).
a) Some issues valuable for comprehensive reconnaissance of the hazard situation (from the ground and the air) are described in materials of wildfire response entities. Those may be ready-to-use manuals to be adjusted to particular kind of situation.
b) Use of the materials requires checking whether they are classified and their sharing among different stakeholders is forbidden.

4) Kinaneva, D., Hristov, G., Raychev, J., Zahariev, P. (2019). 'Early Forest Fire Detection Using Drones and Artificial Intelligence, 42nd International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), pp. 1060–1065, https://ieeexplore.ieee.org/document/8756696:

   a) Comprehensive recognition means reconnaissance in all possible ways. In case of a wildfire this may be done from the ground and from the air.
   b) UAV technologies state modern directions of development for reconnaissance means and methods.
   c) "The UAVs also utilise the benefits from Artificial Intelligence (AI) and are equipped with on-board processing capabilities".
   d) Different scenarios are required to evaluate UAV use in wildfire circumstances.
   e) The effectiveness of UAV use for the reconnaissance purposes depends on operator and receiver of information collected (for example fire service commander).
5) Viegas, C., Chehreh, B., Andrade, J. et al. (2022). 'Tethered UAV with Combined Multi-rotor and Water Jet Propulsion for Forest Fire Fighting', Journal of Intelligent Robotic Systems, 104, p. 21, https://doi.org/10.1007/s10846-021-01532-w:
   a) In general, reconnaissance with the use of UAV may be used for terrain mapping, vegetation mapping, fire detection and monitoring, gathering data for a human decision maker, assisting search and rescue operations and burnt area mapping.
   b) In particular, UAVs may be used for firefighting purposes during the first stage of wildfire development, also simultaneously to reconnaissance.

As regards to firefighting tactics, several sources of information are commonly accessible and may be used for training of participants in preparation and pre-planning activities for wildfire response. They are the following training materials:

1) Firefighter's Handbook On Wildland Firefighting Strategy, Tactics and Safety, 4th Edition. ISBN: 978-0-87939-676-3, https://www.ifsta.org/shop/firefighters-handbook-wildland-firefighting-strategy-tactics-and-safety-4th-edition/36712:
   a) The main idea is to 1) identify situation, 2) adjust available possibilities to the situation, 3) be prepared for situational changes.
   b) The firefighting line is understood as an integral element of the action. It is comprised in firefighters, equipment and operational possibilities.
   c) Firefighter safety is a crucial issue to be taken into consideration when planning firefighting tactics (place of operation, personal protection equipment, operational procedures).

   d) The effectiveness of firefighting tactics is in effectiveness of firefighters who plan the initial attack, set up firefighting lines, prepare defence lines, use water supply points, establish a command system for operations, etc.
   e) The tactics must reflect the fire behaviour and the risk of cascading materialisation effect.
   f) Close cooperation of on-ground teams with air resources is particularly important from the viewpoint of action effectiveness and safety.
2) Wildland Fire Suppression Tactics Reference Guide 1996. National Wildfire Coordinating Group. Standard Firefighting Orders. https://www.nwcg.gov/publications/pms110-18:
   a) Graphical visualisation makes it easier to understand standards of firefighting orders.
   b) Graphical visualisation makes it easier to understand situations requiring vigilance.
   c) Logical connection of the tactics descriptions is important for allowing their remembering by responders (step-by-step formula is reliable when possible).
   d) The tactics must apply both to operational issues (how to put out the fire?) and personal safety issues (what to do and what not to do to go back home in a single non-baked piece?).
3) Szabo, N., Vatrogasna taktika. Zagreb: IPROZ, 2001. (book in Croatian):
   a) Good practices and experience from countries relatively often affected by wildfires may serve as reference for the development of firefighting tactics in other countries.
   b) It is worthwhile to analyse tactics from many countries to find out common issues, operations, tasks, aspects, etc. and to highlight them during training to improve chances for better understanding and cooperation in the future.
   c) International training may establish a platform for building cooperation potential and skills in tactics formulation.
4) Control Measure. Consider appropriate wildfire suppression tactics and develop and implement a tactical plan, https://www.ukfrs.com/guidance/search/consider-appropriate-wildfire-suppression-tactics-and-develop-and-implement:
   a) Tactics should concern a direct attack (a flank attack, a head attack, a tail attack), an indirect attack, an aerial attack and a combination of some, or all of the above.

   b) There is a need to understand a common language describing wildfire scene (a head, a spot fire, a finger, a right flank, a tail, a left flank, an island, a pocket).
   c) The tactics is a derivative of current and predicted fire behaviour and fire spread, scene of operations and terrain, reduced visibility and resources available.
   d) List of reference tactics for different wildfire conditions is useful from the practical viewpoint.
5) Strategy and Tactics, https://www.ifsta.org/sites/default/files/GC_Ch_4.pdf:
   a) It is necessary to understand a common language describing wildfire scene (a head, a spot fire, a finger, a right flank, a tail, a left flank, an island, a pocket).
   b) The tactics may be presented in an incident action plan.
   c) Strategies for direct attack and indirect attack should be visualised.
   d) Anchor point is "(…) a barrier to fire spread where the control action begins" and "Starting the fire line construction from an anchor point is critical to firefighter safety". This is why anchor points are components of the tactics.
   e) Line construction using mechanized equipment is reliable (when possible due to situational conditions).
6) Types and Strategies of Forest Fire Fighting, https://www.waldwissen.net/en/forestry/forest-protection/forest-fires/strategies-of-forest-fire-fighting:
   a) Strategies for firefighting should be focused on "(…) prevention of damage to people, property and assets. In addition, it significantly contributes to environmental protection. Fundamentally, the protection and safety of the operational firefighting force is of prime importance. Necessary firefighting measures, which could put the rescue personnel in danger, should be limited as much as possible".
   b) Operational headquarters (stationary or mobile) is a good organizational practice to effectively coordinate wildfire response.
   c) Firefighting tactics should include ongoing reconnaissance related to protection of people, protection of animals, protection of structures (buildings, streets, utility lines, etc.) and protection of endangered or fast burning vegetation.
   d) Special attention should be paid to ammunition contaminated lands when wildfire occurs. This often requires close cooperation with armed forces and crisis management entities.

The next set of training materials refers to cooperation between firefighting actors. The following sources of information may be used to support training organisers and attendees in this context:

1) ISO 22300:2021 Security and resilience – Vocabulary, https://www.iso.org/standard/77008.html:
   a) It is necessary to be familiar with a common vocabulary concerning security and resilience when talking about cooperation between actors involved in wildfire fighting.
   b) Organisational standards serve be references in shaping a common language for the needs of multi-entity cooperation.
   c) Special attention should be paid to the ISO223… family of standards as they seem to cover several organizational security issues (also security in wildfire conditions, including continuity management regardless of wildfire – see ISO 22301).
2) Multilingual handbook for fire terms across European borders during forest fire fighting. https://ctif.org/library/multilingual-handbook-fire-terms-across-european-borders-during-forest-fire-fighting:
   a) Common organizational and operational language is crucial from the perspective of cooperation.
   b) Common language terms need to be visualised.
   c) Multilingual materials serve as a kind of bridge to common understanding of firefighting entities from different countries.
   d) Cross-border cooperation and international emergency mechanisms (for example UCPM) are basic platforms for the development of cooperation standards and to increase the cooperation potential.
   e) Cooperation should apply to common references for reconnaissance and tactics.
   f) Cooperation between firefighting actors must be based on understanding the mutual operational potential (including equipment) and expectations.
3) European glossary for wildfires and forest fires https://ctif.org/library/european-glossary-wildfires-and-forest-fires:
   a) Creating proper conditions for cooperation between firefighting actors should respect the terminology related to wildfire environment, suppression operations as well as preparation, prevention ad recovery.
   b) International projects may be used for the needs of the cooperation design before a wildfire occurs.

   c) Wildfire co-operators should be familiar at least with the terminology used in a region where they operate (for example in Europe).

4) Euro Fire Multi Lingual Training Tool for Forest Fires, Wild Fires and Vegetation Fires. https://ctif.org/training-and-tools/euro-fire-multi-lingual-training-tool-forest-fires-wild-fires-and-vegetation:
   a) The competency based training system is an effective tool to improve the cooperation potential.
   b) Competency based training system (Eurofire project) was focused on the following objectives: To improve skills and competencies of people, to improve the quality of and access to continuing vocational training, developing relevant and innovative e-learning content, the promotion of social dialogue in vocational training. These indicate directions to strengthen the cooperation also outside the project formula.
   c) The project formula is a proper way to prepare multi-lingual materials for the purposes of the cooperation design and improvement.
5) Firefighting intervention management UVI (software tool, available only in Croatian): https://hvz.gov.hr/istaknute-teme/informatizacija/sustav-upravljanje-vatrogasnim-intervencijama/101:
   a) A valuable way of improving cooperation between firefighting actors is to connect efforts of the main executors (fire service) and the main managers (public administration).
   b) An improvement in cooperation may be a derivative of firefighting action standardisation, information unification and distribution, a unified reporting, a common use of IT support tools.
   c) Cooperation is built on common knowledge based on response resources, hazardous materials and the resources location related to the warning system and vehicle tracking system.
6) Paveglio, T. B., Abrams, J., Ellison, A. (2016). 'Developing Fire Adapted Communities: The importance of Interactions Among Elements of Local Context', Society & Natural Resources, 29(10), pp. 1246–1261, http://dx.doi.org/10.1080/08941920.2015.1132351:
   a) Cooperation should consider also citizens.
   b) Societal perception of the hazard must be calculated into the overall wildfire risk (risk perception is an integral element of the risk).
   c) Every community has a unique social and societal profile that may be used to enhance the cooperation potential.

7) Paveglio, T.B., Edgeley, C.M. (2020). 'Fire Adapted Community' In: Manzello, S.L. (eds) Encyclopedia of Wildfires and Wildland-Urban Interface (WUI) Fires. Springer, Cham. https://doi.org/10.1007/978-3-319-52090-2_114:
   a) "A fire adapted community (FAC) is comprised of residents, land management professionals, local politicians, emergency managers, and fire professionals who collaborate effectively to plan for, respond to, and recover from the evolving risks that fires pose to humans within or outside of the Wildland Urban Interface".
   b) Cooperation should consider first of all citizens.
   c) Every community has a unique social and societal profile which may be used to boost the cooperation potential. An organisational dimension of a community is a good reference to design effective societal cooperation.

During the course of the research, the need arose of establishing a general category of training materials. This applies to sources of information that may be used for different phases of wildfire response given the current needs and expectations. The following items are enumerated in this category of training materials:

1) Majlingova, A., Kucikova, D., Kropil, R., Hancko D. (2022). 'Wildland fire patterns and fire-fighting tactics in Central European Countries'. Zvolen: Technical University in Zvolen:
   a) Dynamics of wildfires determines the firefighting tactics and disaster management conditions.
   b) Fire consequences may generate the necessity of involving multiple responders to undertake common efforts to face the fire and relevant secondary threats.
   c) Broad spectrum of firefighting tactics that may be tailored to (i.a.) the current phase of wildfire development and terrain conditions.
   d) ICT and geoinformation technologies find their application in responding to wildfires.
2) Restas, A. (2022). 'Drone swarm technology as a competitive alternative to traditional aerial firefighting'. In. Advances in Forest Fire Research, Viegas, D. X., Ribeiro, L.M. (eds). University of Coimbra: Coimbra, pp. 1612–1615:
   a) Drones are a very promising alternative to classic aircraft when fighting wildfires .

b) The swarm formula is the next significant step in the common use of drones for wildfire response purposes.
c) The use of drones requires specific calculation methods to ensure sufficient amount of extinguishing medium for wildfire response.
d) Proper coordination between drone operators and other wildfire response actors is crucial for extinguishing efficiency and safety reasons.

3) Stefanou, N., Kazantzidou-Firtinidou, D., Sakkas, G., Theodoridis, G., Rousakis, V. (2022). 'Training and exercises for Critical Infrastructure – A Hellenic computer-assisted exercise use case analysis', International Journal of Disaster Risk Reduction, 69, p. 102729, https://doi.org/10.1016/j.ijdrr.2021.102729:
   a) Computer-assisted exercises have a high educational potential.
   b) Computer-assisted tools need to match operational needs of wildfire response.
   c) Training materials may cover all phases of the training, namely identification and analysis of needs, training planning, training delivery, training evaluation, assessment and lessons learned.
4) Be Prepared for a Wildfire, https://community.fema.gov/ProtectiveActions/s/article/Wildfire:
   a) Webpages of leading international security institutions serve as valuable information sources and may be used for wildfire response training.
   b) The hazard information sheet contains basic set of information to supplement the training content.
   c) Data about additional information sources may give participants more possibilities to gain further knowledge, also after the training.
5) Wildfire. Response Planning (Evacuation), https://community.fema.gov/ProtectiveActions/s/article/Wildfire-Response-Planning-Evacuation:
   a) Local fire evacuation plan is a good example of a solution that may be kept by training participants after the training, reminding them of crucial training issues.
6) Mojir, K.Y., Olson, N., Balogh, Z., Maceviciute, E., Gatial, E. (2023). Citizen Engagement in wildfire management: needs, challenges, methods and framework. Yousefi Mojir et al. Citizen Engagement in wildfire management. *WiPe Paper – Track 10: Volunteers in Crisis Management/Emergency Response. Proceedings of the 20th ISCRAM Conference* – Omaha, Nebraska, USA May 2023, J. Radianti, I. Dokas, N. LaLone,

D. Khazanchi, eds. https://idl.iscram.org/files/mojir/2023/2564_Mojir_etal2023.pdf:

a) New technologies provide new possibilities in support of wildfire management, including wildfire response.
b) New media and personal devices amplify citizen potential to engage accordingly in wildfire management, including wildfire response. Several engagement patterns are worked out and tested.
c) ICT platform is a kind of perspective solution to integrate multiple technologies for wildfire response.
d) Sensors, communication devices, robots and drones are good examples on how to use new technologies in wildfire response.

7) Gromek, P. (2021). 'Strategic training and exercises for critical infrastructure protection and resilience: A transition from lessons learned to effective curricula', International Journal of Disaster Risk Reduction, 65, p. 102647, https://doi.org/10.1016/j.ijdrr.2021.102647:
   a) Training may be based on general decision-making process comprising an analysis of decision-making process, decision problem formulation, working out alternative solutions to the decision problem, analyses of available alternatives, choosing a reference solution to the decision problem, implementation of the solution and relevant evaluation.
   b) Training materials should contain background information, real information and templates.
   c) The materials should match issues related to trainers, trainees and equipment, commonly constituting effective training curricula.
8) Innovation in Crisis Management, Fonio, C., Widera, A., Zwęgliński, T. (eds). Routledge:
   a) Trials define valuable forms of combined training and technology evaluation.
   b) Training courses and trials need to be based on precisely identified needs of practitioners to reflect real operational needs and expectations.
   c) New technologies are crucial to effectively shape situational picture and enhance situational awareness with regard to emergencies, disasters and crisis situations (including these triggered by a wildfire).
   d) Trials and training courses should be based on methodologies to reflect state-of-the-art and best educational and evaluation practices.

9) The Trial Guidance Methodology, Project Driver+, https://www.driver-project.eu/wp-content/uploads/2020/02/TGM-handbook-FINAL.pdf:
   a) Complex materials should be properly described to improve chances for being understood by a reader (for example a bird's-eye view on the material, idea/approach description, summary).
   b) The graphical layer is a key issue of attractive material.
   c) Step-by-step approach is crucial in training of adults (training reason and objectives).
10) Heikkila, T. V., Gronqvist, R., Jurvelius, M. (2010). Wildland Fire Management. Handbook for Trainers. Rome: Food and Agriculture Organization of the United Nations:
   a) Background and justification for intensified wildfire activities.
   b) Baseline data for wildfire control.
   c) Organisation of wildfire control.
   d) Fire prevention.
   e) Wildfire behaviour.
   f) Pre-suppression activities.
   g) Equipment.
   h) Suppression tactics and techniques.
11) Teie, W.C. (2018). Firefighter's Handbook On Wildland Firefighting Strategy, Tactics and Safety. 4th Edition. Stillwater: Oklahoma State University:
   a) Fireline safety.
   b) Fire weather
   c) Topography and fuels.
   d) Wildfire behaviour.
   e) Fireline construction
   f) Use of water and fire.
   g) Use of firefighting resources.
   h) Initial attack: strategies and tactics.
   i) Wildland/Urban firefighting: strategies and tactics.
   j) Incident command system.
   k) Firefighting realities.
   l) Map reading.
   m) Fire prevention.
   n) Identification of hazardous materials.
   o) Use and care of hand tools.

It is worth highlighting that training materials identified during the research are simple a reference for the materials compiled and shared for the purposes of multiple kinds of training for wildfire response. As a rule, every training course is unique and requires specific materials for trainers and participants. Consequently, different forms of training materials should be taken into account. The following reference list of these forms needs to be considered when planning and delivering the training:

1) books,
2) research papers,
3) leaflets,
4) legal acts,
5) procedures,
6) guidelines,
7) operational manuals,
8) standards,
9) simulation results,
10) case studies,
11) action analyses,
12) reports from exercises,
13) reports from trials and technology pilots,
14) statistics,
15) maps and pictures,
16) technology demonstrators,
17) videos.

Every training should be optimised from the perspective of training materials prepared for and shared among participants. The time necessary for familiarisation with the materials needs to be relatively short but long enough to compile information crucial for achievement of the training goals. It may be challenging when new technologies are considered but necessary to maximise the educational effect of a training. If relatively complex material is expected, an e-learning preliminary course (organised before the core training part) can facilitate the process of information sharing and knowledge development.

Chapter 4. SILVANUS technosphere and support of preparation and pre-planning activities for wildfire response

4.1. Detection technologies

A very important part of SILVANUS technosphere is constituted by detection technologies. Those are solutions that allow immediate notification of the hazard occurrence in difficult terrain conditions. They are based on multiple items under the common names ‘sensors’ or ‘detectors’. Sensors and detectors can be technical devices as well as information sources monitored by specialised algorithms.

SILVANUS project delivers following detection technologies (SILVANUS, 2024):

1) fire detection based on social sensing,
2) fire detection from IoT devices,
3) fire detection at the Edge.

Fire detection based on social sensing is developed to integrate and use social tools to notify and communicate a fire. The significant role in social sensing is played by social media and tools related to social media (Aggarwal, Abdelzaher, 2012). They commonly constitute a kind of a sensing network. Wherever social media user equipped with relevant device is present, detection potential is noticed there.

The general rule describing fire detection based on social sensing is that at least the approximate location of the hazard is located regarding an analysis of social media content. It should comprise pictures, photos, tweets, posts, messages, and other elements containing or referring to the word ‘fire’ and its similarities (for example ‘smoke’, ‘heat’, ‘flames’, ‘danger’).

Figure 20 presents an illustrative public post of a member of the city council for the Municipality of Nové Mesto (Bratislava), which was used for identification of hazard location.

The potential of fire detection based on social sensing is observed with preparation and pre-planning activities. Table 21 presents a synthetic view of possibilities for the use of fire detection based on social sensing in the context analysed. It refers to particular phases of wildfire management (directly to phase A, and indirectly to phases B and C).

Table 19. Fire detection based on social sensing and wildfire management phases

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase A *(preparation and preparedness)*	Delivering information about hazard occurrence. Enabling the locating of a hotspot. Raising public awareness and communication.
Phase B *(response)*	Real-time monitoring of situation. Identifying secondary threats.
Phase C *(reconstruction and recovery)*	Identifying deviations from reconstruction and recovery plans. Notifying of secondary threats.

Source: own study

Figure 21. Illustrative public post of a member of the city council for the Municipality of Nové Mesto, Bratislava

Source: (SILVANUS D4.2, 2023)

Fire detection based on social sensing is a solution typically dedicated to preparation and preparedness to a wildfire. It presents the perspective of social media user who witnesses a situation of danger. The location of the user can be misleading with respect to location of a hazard. This may be a significant challenge for wildfire responders to precisely set out the danger zone. This aspect should be reflected in training as well.

Specifics and functionalities of fire detection based on social sensing determine how to use them during a training to prepare and pre-plan for wildfire response.

Results of a technology analysis and demonstrations (pilots) allow formulating the following training guidelines:

1) Fire detection based on social sensing is a valuable tool to achieve training objectives related to notification of a hazard (a fire) and general localisation of a hotspot. It can also facilitate the detection of secondary hazards (other fires as well as other kinds of fire-related factors).
2) The reference training scope can cover early detection systems, detection procedures, reducing ‘false-positives’ generated by other detection devices, citizen engagement in wildfire response, crisis communication, risk communication, and cooperation with edge-technologies (for example drones and robots).
3) A general description of the tool functionalities can be executed via lecture, talk, and technology presentation. A significant part of training needs to be focused on self-operating of the tool and using it in accordance with the training scenario. The scenario should reflect real detection problems that can be noticed especially during the first phase of wildfire development with respect to lack of information, information chaos and the necessity of confirming the preliminary detection result.
4) The following training materials are recommended, which may be helpful in achieving training goals with the use of fire detection based on social sensing:
   a) general technology leaflet,
   b) description of detection procedure (in the ‘step-by-step’ formula),
   c) photos,
   d) social media content (for example tweets),
   e) pre-defined information on other detection results (for example from the field sensors).
5) Direct presence of technology provider is desirable but not mandatory (especially if a set of valuable training materials is shared among participants before and after a training course). Online consultation is acceptable.

Fire detection from IoT devices is based on a network constituted by a set of sensors (detectors). In other words, the technology connects IoT devices into a detection network. It finds its application in disaster preparedness and forecasting (Pallai et al., 2021), analysing of disaster scenarios (Sacco et al., 2020) shaping virtual infrastructure for disaster situations (Abdellatif et al., 2023), and detecting fire disasters in the woods (Cui, 2020).

The main functionality of IoT devices dedicated for fire detection is to use sensors to identify one or more of wildfire manifestations – for example smoke, flames, hot spot, etc. The detection range is limited by technology constraints. However, information about the geolocation of a detector and angle of the detected signal can facilitate the setting out of a general direction to be investigated (for example by field troops). This manner of operation is quite similar to detection towers commonly used in Europe but also relatively cheaper (see simple webcam system for fire detection (Restas et al., 2022).

Multiple IoT devices can be integrated into a sensing network. Figure 22 presents an illustrative solution developed specifically in the SILVANUS project to detect a wildfire[1].

Figure 22. IoT element designed to detect a wildfire

Source: (SILVANUS, 2024)

Potential of fire detection from IoT devices is observed when considering preparation and pre-planning activities. Table 20 lists reference relations of the technology with particular phases of wildfire management (directly to phase A, and indirectly to phases B and C).

[1] This technology is in the early stage of development. Its common use in forest conditions is complicated due to the limited area of sensing and the necessity of deploying a big number of sensors. Its usefulness increases in protection of critical infrastructure in a forest. However, it is possible to attach the device to a tree. Two kinds of detectors are integrated (there could be more if necessary). A protection cover and own batteries are deployed. The device can be integrated with machine learning algorithms to reduce the risk of 'false-positives' due to weather conditions in the woods.

Table 20. Fire detection from IoT devices and wildfire management phases

Wildfire management phase	Reference relation to preparation and pre-planning activities for wildfire response
Phase A *(preparation and preparedness)*	Delivering information about hazard occurrence. Allowing the finding of a hotspot (within the detection range of a device). Allowing ascertaining of the direction in which a hotspot should be searched (outside the detection range of a device). Feeding machine learning algorithms to reduce the risk of ‘false-positives’.
Phase B *(response)*	Real-time monitoring of hazard development (by analysing activations of next devices).
Phase C *(reconstruction and recovery)*	Notifying of secondary threats. Compiling information about weather conditions in the woods to be deployed in reconstruction and recovery strategies).

Source: own study

Fire detection from IoT devices is dedicated to preparation and preparedness phase of wildfire management. It may be a valuable tool to support wildfire management regarding other management phases. As it is focused on the preparation and pre-planning activities, IoT devices provide information about the occurrence of a hazard and the relevant location. Activations of other devices could mean the development of hazard situation with positive input on shaping situational awareness. However, IoT devices are Internet-related and require reliable connection to the wildfire management network. This may be a serious challenge for their common use in the woods.

The specifics and functionalities of fire detection from IoT devices determine how they could be used during a training course to prepare and pre-plan for wildfire response. The following training guidelines can be formulated on the basis of results from technology analyses and demonstrations (pilots) organised under the SILVANUS project:

1) Fire detection from IoT devices is a valuable tool to allow achieving training objectives related to notification of a hazard (a fire), direct or indirect localisation of a hotspot (direction in which a hotspot should be searched).

It can facilitate monitoring of hazard development (via analysing activations of other devices in the woods).

2) The reference training scope can cover early detection systems, detection procedures, reducing ‘false-positives’ generated by other detection devices and social sensing solutions, confirmation of detection alert, risk communication, and cooperation with the-edge-technologies (for example UAVs and robots).
3) Lecture, talk and technology presentation are appropriate ways of making a general outline of the tool and its functionalities. The essential part of a training course needs to be focused on inserting the devices, controlling their operation, monitoring the alerts and interpreting them. The training scenario should reflect such detection issues as the necessity to confirm preliminary detection result (for example from another sensor), respecting weather conditions in the woods, and monitoring of hazard development.
4) The following training materials are recommended to support training with the use of fire detection from IoT devices:
   a) general technology leaflet,
   b) description of detection procedure (in the ‘step-by-step’ formula),
   c) photos,
   d) pre-defined information on other detection results (for example from the field sensors).
5) The direct presence of a technology provider is mandatory. Such a person needs to be prepared to answer questions related to, especially, to the operational manual and alert interpretation.

Fire detection at the Edge is a specific deployment of Artificial Intelligence (AI) in wildfire response. ‘The Edge’ means the real placement of data/information sources at the technical endings of a detection system. Typically, those are sensing devices. AI integrates data/information flows. It allows analysing data and information to acquire new information crucial for response. The reference ones comprise the fact of occurrence and exact location of a hotspot. The technological potential of fire detection at the Edge is expressed by other integration possibilities of AI. AI-powered UAVs and the IoT devices are worth of mentioning (Ramadan et al., 2024)

As regards the general operational rule of fire detection at the Edge, analytical algorithms (computer vision) are integrated with data/information collected by IoT devices. Photos and movies compiled from the ground (robots) and the air

(UAVs) are used as input of the algorithms as well. They commonly determine hazard detection capabilities that are connected to a communication system (for example to the Internet or satellite system). This allows analysing video and sensor data to confirm the fire outbreak in the woods. However, fire detection at the Edge requires training related to computational algorithms before the system may be launched in the field. It is specific for machine learning and AI in general.

Figure 22 presents a visualisation of a danger zone (smoke) and hotspots after the use of fire detection at the Edge (the view from a UAVs).

Figure 22. Visualisation of danger zone (smoke) and hotspots after the use of fire detection at the Edge (the view from a UAVs)

Source: (SILVANUS, 2024)

The potential of fire detection at the Edge is noticeable as preparation and pre-planning activities are considered. Table 21 contains information on the technology relations to particular phases of wildfire management (directly to phase A, and indirectly to phases B and C).

Table 21. Fire detection at the Edge and wildfire management phases

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase A *(preparation and preparedness)*	Providing information on the occurrence of a hazard. Allowing the localisation of one or more hotspots. Allowing the location of smoke area range.
Phase B *(response)*	Real-time monitoring of hazard development (by analysing the location of hotspots and area of smoke logging). Notifying of secondary fires.
Phase C *(reconstruction and recovery)*	Compiling information about progress of reconstruction and recovery on the basis of additional AI algorithms.

Source: own study

Fire detection at the Edge is dedicated to the preparation and preparedness phase of wildfire management with potential to support wildfire management in other management phases (response and reconstruction and recovery phase). As regards the preparation and pre-planning activities, the Edge detectors provide information about the materialisation of a hazard along with relevant location (zone). The technology works as a network so that a composite situational picture can be obtained, new devices may be integrated and new algorithms are applicable to enhance its operational potential in wildfire response.

Specific features and functionalities of fire detection at the Edge determine ways of their use during training to prepare and pre-plan for wildfire response. The following training guidelines can be formulated on the basis of results from a technology analysis and demonstrations (pilots) organised in the SILVANUS project:

1) Fire detection at the Edge is a promising tool for achieving training objectives related to notification of a hazard (a fire, a smoke), direct localisation of a hotspot, general localisation of a smoke area, and an analysis of secondary threats (for example new hotspots). The technology can facilitate the monitoring of hazard development on the basis of an overall view of the situational picture in the danger area.
2) The reference training scope can cover early detection systems, detection procedures, mapping of a danger zone, reducing ‘false-positives’ generated by other detection devices and social sensing solutions, confirming

the detection alert, risk communication, as well as cooperation with the edge-technologies (for example UAVs and robots), decision support systems and cooperation between firefighting actors firefighting actors.

3) Lecture, talks and technology presentation are proper ways to generally describe the tool and its functionalities. Special attention should be paid to case studies to demonstrate ways of interpreting detection results. The technology can be also used as a supplementary way to handle table top exercises and apply the classical problem method and decision games. Its integration potential may be used to conduct a training simultaneously with technology demonstrations and trials.
4) The following training materials are recommended to support the training with the use of fire detection at the Edge:
   a) general technology leaflet,
   b) description of detection procedure (in the 'step-by-step' formula),
   c) description of rules concerning results interpretation with examples,
   d) description of case studies,
   e) pre-defined information pertaining to other detection results (for example from the field sensors).
5) Direct presence of technology provider during a training course is mandatory to demonstrate the operational manual and to provide advice on detection interpretation.

Detection technologies are valuable tools for training oriented at preparation and pre-planning activities. They may be used to compile essential information to initiate wildfire response. The form of technology network increases their operational robustness and leverages organisational flexibility of such training. This means that detection information may be shared and relevant skills can be developed in multiple ways, with the use of several technologies and in different configurations of training objectives, forms, methods and materials.

4.2. Computational tools

New technologies typically mean new and wider possibilities to gather, analyse, transfer and use data for wildfire response purposes. New algorithms, methods of collecting data and computational mechanisms provide new knowledge and allow make decisions quicker, easier and with a high rationality level. Consequently, computational tools play a significant role when supporting wildfire response. They make it possible to preliminarily prepare for firefighting action and may supplement reconnaissance activities to allow obtaining a complete situational picture. They are valuable solutions also to predict hazard development and become prepared for the most probable or the riskiest wildfire scenarios.

SILVANUS project delivers the following computational tools (SILVANUS, 2024):
1) fire danger risk assessment tool,
2) fire spread forecast,
3) biodiversity profile mobile app.

The fire danger risk assessment tool is used to calculate the fire risk in a given area. It allows comparing different areas and diverse sets of conditions. This makes it possible not only to determine the current fire situation but also to foresee probable changes in these conditions and multiple fire scenarios. The index reflects the fire risk, which is a specific derivative of the probability and consequences of a fire. The risk provides more information to situational awareness than only the probability of consequences as it cognitively connects the two of them.

The fire danger risk assessment tool calculates the risk value on the basis of information that is essential to ascertain what is going on and how it could develop in the nearest future. The tool makes an analysis of weather data (i. e. 2-metre temperature, 10 m wind u component and wind v component, total precipitation, and relative humidity), information about vegetation (Leaf Area Index, Vegetation Index from satellite products (Copernicus Sentinel Products)), land cover (Copernicus data), topography of the area (SAR satellite data or from static land survey maps), and historical data about burnt areas. Its strength is the possibility of visualising calculation results on a map.

Figure 24 presents illustrative results obtained with the use of the fire danger risk assessment.

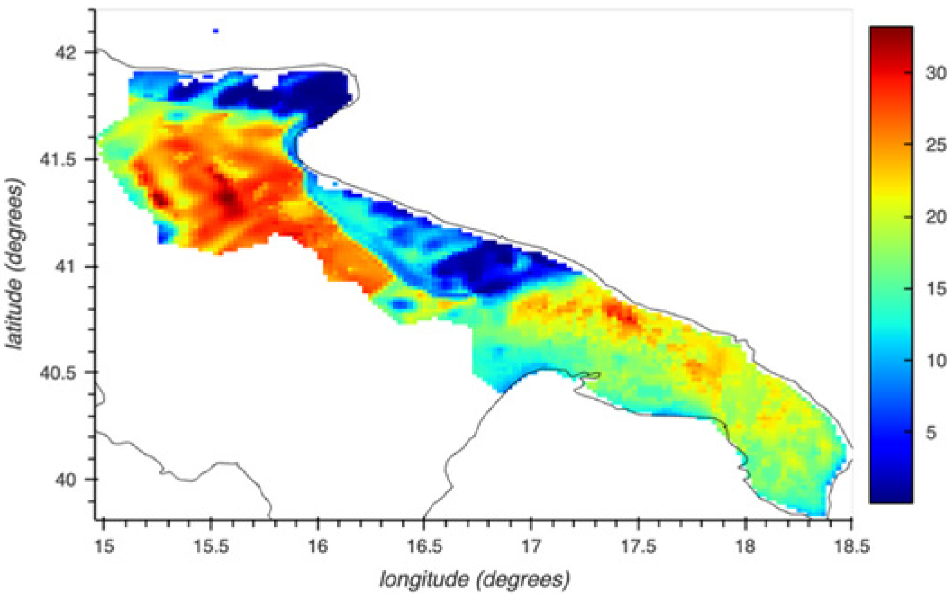


Figure 24. Illustrative results obtained with the use of the fire danger risk assessment tool

Source: (SILVANUS, 2024)

The potential of the fire danger risk assessment tool is noticeable when preparation and pre-planning activities are taken into consideration. Table 22 presents a synthetic view of possibilities of deploying the tool in particular phases of wildfire management (directly to phase A, and indirectly to phases B and C).

Table 22. Fire danger risk assessment tool and wildfire management phases

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase A *(preparation and preparedness)*	Compilation and integrating complex information about a fire scene. Providing information about the fire risk. Prioritising preparation and preparedness activities on the basis of fire risk and its terrain distribution. Analysing different fire scenarios and fire situation in different regions. Optimising the distribution of resources (firefighters, engines, helicopters, pumps, etc.). Raising situational awareness.

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase B *(response)*	Real-time monitoring of the fire situation. Identifying secondary threats. Adjusting firefighting tactics to wildfire forecast. Raising situational awareness.
Phase C *(reconstruction and recovery)*	Effectiveness monitoring for reconstruction and recovery activities. Notifying of secondary threats.

Source: own study

The highest cognitive value related to using the fire danger risk assessment tool is noticeable for the first phase of wildfire management. Risk value and terrain risk distribution seem to be strengths of this tool when shaping the situational awareness, and these strengths are the most important in preparation and preparedness for wildfire response. From the theoretical point of view, the tool can be implemented for every terrain. Its only limitation are data accessible and information collected. Training, as a method of preparation and pre-planning activity for wildfire response, should reflect this constraint.

The specifics and functionalities of the fire danger risk assessment tool shed light on its use during a training course to prepare and pre-plan for wildfire response. A technology analysis and demonstrations (pilots) provide a background to specify the following training guidelines:

1) The fire danger risk assessment tool may facilitate achieving training objectives related to raising situational awareness, determining the riskiest parts of the given area, verifying alternative fire scenarios, analysing the hazard development, optimising the dispersal of resources and shaping cooperation needs.
2) The reference training scope can cover shaping of situational awareness, early detection systems, detection procedures, a selection system for equipment with vehicles, equipment and extinguishing agents for extinguishing wildfires, risk communication, mapping, and cooperation between firefighting actors firefighting actors.
3) A general description of the tool functionalities can be obtained via lecture, talk, discussion, and technology presentation. A significant part of a training course needs to be focused on self-operation of the tool and its using

to achieve the desired training goals. Case studies are valuable training methods to verify whether the training participants know how to use the tool in practice.

4) The following training materials may be recommended, which may prove to be helpful in achieving training goals with the use of the fire danger risk assessment tool:
   a) general technology leaflet,
   b) outline of the calculation procedure (in the 'step-by-step' formula),
   c) maps,
   d) GIS system,
   e) pre-defined information as input for this tool.
5) The direct presence of technology provider is desirable but not mandatory. Good preparation of training materials can be sufficient to equip training participants with basic information on how to use the tool in practice. The mapping functionality allows visualising calculation results without any specific difficulties and is intuitive.

The second computational tool is the **fire spread forecast**. It stems from simulations of how the hazard may develop in the given weather and terrain conditions (Szajewska, 2024). This is the next example on how to predict the occurrence and development of a hazard, and use this knowledge to prepare and pre-plan for wildfire response. Fire spread is relatively broad cognitive concept. Consequently, the forecast can be expanded by input of multiple information. All the compiled information is important to indicate the most probable direction of fire movement (Artes et al., 2015; Szajewska, 2024).

The SILVANUS project was used to work out a valuable fire spread forecast tool to combine different sources of information, and to analyse them in an integrated way to investigate hazard development scenarios. The SILVANUS idea takes into consideration such information as terrain elevation, slope and other aspects, atmospheric temperature, wind speed and direction, fuel type, moisture, canopy characteristics, results of firefighter efforts (for example air extinguishing, defence lines), demineralised belts, road system, water reservoirs and bodies of water, and current location of the fire front (SILVANUS, 2024). A very important issue is to present ranges of the hazard zone in different time perspectives. This allows optimising the use of resources and preliminarily verify their relevance to the projected conditions.

Multiple wildfire sources determining wildfire ranges are presented on figure 25. These maps were obtained with the use of the fire spread forecast tool.

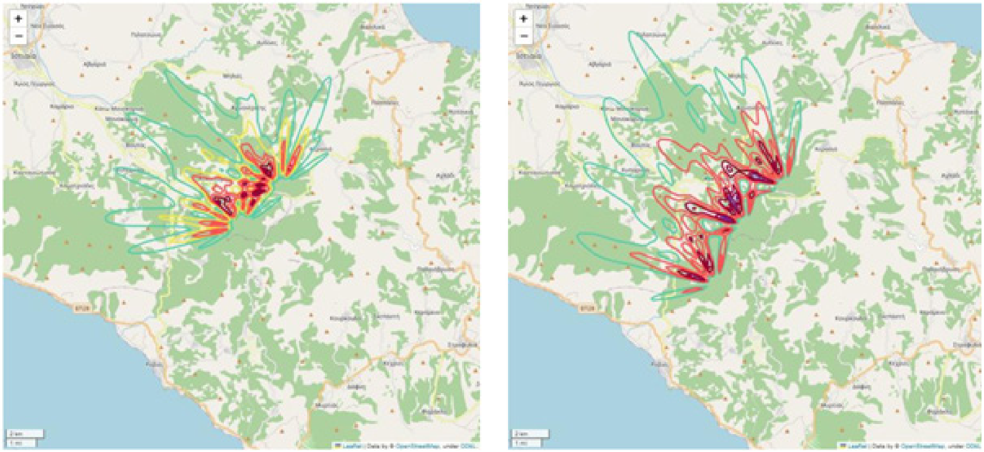


Figure 25. Multiple wildfire sources determining wildfire ranges

Source: (SILVANUS D5.3, 2023)

Specifics of preparation and pre-planning activities stay in line with potential of fire spread forecast tool. A general view on possibilities of using this computational tool is presented in Table 23. These possibilities are related to particular phases of wildfire management (directly to phase A, and indirectly to phases B and C).

Table 23. Fire spread forecast tool and wildfire management phases

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase A *(preparation and preparedness)*	Compiling and integrating multiple information about a fire scene. Providing information about fire behaviour patterns. Prioritising preparation and preparedness activities on the basis of the fire spread forecast. Analysing different fire scenarios and fire situation in different regions. Optimising the distribution of resources (firefighters, engines, helicopters, pumps, etc.). Raising situational awareness.

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase B *(response)*	Real-time monitoring of fire situation. Identifying secondary threats (including the synergy effect in wildfire development). Adjusting firefighting tactics to wildfire forecast. Raising situational awareness.
Phase C *(reconstruction and recovery)*	Effective monitoring to assure appropriate conditions for reconstruction and recovery activities. Optimising the reconstruction and recovery strategies to handle future conditions of a wildfire. Notification of secondary threats.

Source: own study

The fire spread forecast tool may be applied in all wildfire management phases. However, it seems to be of biggest interest for phase A (preparation and preparedness). It allows the execution of complex calculations including the integration of multiple data sources and information. Consequently, the tool may noticeably enhance situational awareness, and this is an issue of particular importance when talking about preparation and pre-planning activities for wildfire response. As it is a kind of computational solution, the effectiveness of its use relies on available data and information implemented. This also determines the use of the tool in the training processes.

The fire spread forecast tool is specific and is characterised by valuable computational functionalities. The two need to be taken into account when considering a training course for preparation and pre-planning for wildfire response. The technology analysis and demonstrations (pilots) provide a background to express the following training guidelines:

1) The fire spread forecast tool can provide support in matching training objectives related to raising situational awareness, determining risky parts of the given area (the parts that are not in flames yet but may be soon), verifying alternative fire scenarios, analysing hazard development, optimising the dispersal of resources and shaping cooperation needs.
2) The reference training scope can cover shaping the situational awareness, resources management (including vehicles, equipment and extinguishing agents for extinguishing wildfires), dispatch and effective delivery

of resources to the wildfire scene, risk communication, mapping, firefighting tactics, and cooperation between firefighting actors.

3) General description of the tool functionalities can be done via lecture, talk, discussion and technology presentation. A significant part of a training course needs to be focused on self-operating of the tool and its using to achieve training goals. Case studies are valuable training methods to verify whether training participants know how to use the tool in practice. Pre-defined data are required to prepare the case study formula and use it effectively. Integration with GIS solutions will expand the analytical potential of the tool described.
4) The following training materials may be recommended, which may prove to be helpful in achieving training goals with the use of the fire spread forecast tool:
   a) general technology leaflet,
   b) description of the analysis procedure (in the 'step-by-step' formula),
   c) description of case studies,
   d) maps,
   e) GIS system,
   f) pre-defined information as input for this tool.
5) The direct presence of technology provider is desirable but not mandatory. Good preparation of training materials should be sufficient in this case. The mapping functionality allows visualising of calculation results without any specific difficulties and is intuitive. As the calculation procedure may be complex, it is necessary to use the 'step-by-step' formula in training organisation (to integrate training steps into calculation steps when the tool is used).

Biodiversity profile mobile app is used to analyse biomass structure and distribution in the given area – area which may be affected by a wildfire. At the highest level of generality, biodiversity means knowledge about tree species and their location. As trees differ in combustible properties, their particular species determine the fire characteristics and the fire load in the woods. This plays an important role in analysing the vulnerability of a forest to a fire, and consequently may leverage the fire risk.

The general idea of biodiversity profiling in the SILVANUS project is to get to know the plant species (especially trees) in the zone of potential danger. This is possible thanks to a mobile application called 'Woode'. As the main assumption, the application is to be available for field firefighters and other wildfire responders to compile information about biodiversity by on-field scanning of leaves. Information about leaves allows recognising species of plants. It may serve as input to other computational solutions to calculate the fire load and biomass distribution, and then to feed the computational forecast tools and risk assessment solutions.

Figure 26 illustrates the Woode screen.

Figure 26. View on the Woode screen

Source: (SILVANUS, 2024)

The biodiversity profile mobile app corresponds indirectly to preparation and pre-planning activities for wildfire response. It is more a functionality than a standalone solution, so its potential as input is expressed (the use of the tools allows to "feed" other computational tools). The general view of a possible use of this computational tool is presented in Table 24, with close relationship to particular phases of wildfire management (phase A, phase B and phase C).

Table 24. Biodiversity profile mobile app and wildfire management phases

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase A *(preparation and preparedness)*	Compiling information about biodiversity on the fire scene. Supporting calculations of biodiversity distribution and fire load. Analysing the vulnerability of the woods to a wildfire. Raising situational awareness.
Phase B *(response)*	Identifying secondary threats (highly vulnerable areas). Adjusting firefighting tactics to biodiversity distribution and fire load. Raising situational awareness.
Phase C *(reconstruction and recovery)*	Effectiveness monitoring of reconstruction and recovery processes. Notifying secondary biodiversity-related threats.

Source: own study

The use of the biodiversity profile mobile app has an indirect impact on preparation and pre-planning activities for wildfire response. However, it may facilitate the effective deployment of other computational tools. The tool users can have a preliminary view on the fire load in the given area on the basis of analysis results. The data collected can be transferred also to command centres or other analytical units for further investigation. It may serve as input to the risk assessment and fire spread forecast. However, this requires in-depth technology integration, which should remain in line with training purposes and expectations.

The biodiversity profiling functionality can be successfully described and used in training for wildfire response. The relevant app is characterised by a simplicity of installation and may be downloaded on every mobile device. On the basis of technology analysis and demonstrations (pilots), the following training guidelines may be specified to achieve this goal efficiently and with positive impact on the educational effect:

1) The biodiversity profile mobile app can provide support in matching training objectives related to raising situational awareness, appointing vulnerable parts of the given area (the parts characterised by relatively high fire

load), analysing the development of the hazard, fire risk assessment, optimising the distribution of resources, and in field reconnaissance activities.
2) The reference training scope can cover shaping situational awareness, dispatch and effective delivery of resources to the wildfire scene, risk communication, risk assessment, firefighting tactics, and cooperation between firefighting actors.
3) General description of the tool functionalities can be done via lecture, talk, discussion, and technology presentation. A significant part of training needs to be focused on self-operation of the tool in the woods. Practical exercises and field exercises are especially desirable. The attendee must be able to use biodiversity profiling functionality in practice, also after launching of own mobile device. When the app is used in other computational processes, the participant should know how to properly compile interesting information and serve as input for other computational tools.
4) The following training materials are recommended to achieve training goals with the use of Biodiversity profile mobile app:
   a) general technology leaflet,
   b) book with types and patterns of leaves,
   c) book with case studies,
   d) description of the analysis procedure (in the ‘step-by-step’ formula).
5) The direct presence of a technology provider is desirable but not mandatory. Good preparation of training materials should be sufficient in this case. When training requires direct access to the technology provider, the ‘train the trainers’ formula can be applied to prepare training organisers to support trainees in technical activities (for example to download the app, to install the app, to interpret analysis result, etc.).

Computational tools may play a significant role in preparation and pre-planning activities for wildfire response. A number of tools and technologies may be used to comprehensively compile and effectively use data and information. The primary issue is to determine the situational picture that reflects real conditions in the woods and of the wildfire. It may be done in multiple ways, depending on technology and training purposes. Furthermore, calculation tools allow to get information about a hazard before it occurs, as well as during its development. Consequently, wildfire response can be shaped on scenario-based strategies and tactics, with a potentially positive influence on the response success. All computational aspects can be learnt to enhance preparation for wildfire response.

4.3. End-technology tools

End-technology tools are machines, devices as well as their sets and systems that are physically situated on the scene or close to the scene of firefighting action. They often provide platforms for sensors, cameras and other equipment necessary for wildfire response. Their integratory role is highlighted. Deployment of end-technology tools to training processes may prepare trainees to use the tools in real conditions of a fire in the woods without technology-related stress as well as with limited manual and technical constraints.

Among SILVANUS solutions, four kinds of end-technology tools are developed. They are as follows (SILVANUS, 2024):
1) UAVs,
2) robots,
3) the forward command centre,
4) MESH-in-the-Sky.

The operational potential of **UAVs** is impressive when considering fire protection in the woods (Feltynowski, Zawistowski, 2018; Szajewska, 2020; Fellner, 2023). Apart from classical reconnaissance tasks, they are used also for firefighting purposes (Restas, 2022). Technology development provides new solutions to make them more powerful, lighter, more operational and better equipped. Consequently, UAVs are said to operate as mobile sensing platforms and extinguishing points. Their functionality to fly in a swarm may additionally increase relevant abilities, with positive impact on wildfire response and activities ascribing into other wildfire management phases (Restas, 2022).

As a rule, a UAV is identified as an unmanned aerial vehicle, which is a kind of simplification (as compared to unmanned ground vehicles that are typically called ‘robots’). It is a platform connected with an operator or an operational centre, and equipped with certain devices. The UAV itself allows getting an ‘in-air’ view on the wildfire scene. This is its essential functionality. The devices define additional UAV functionalities. Exemplifying, they could be making photos, recording videos, detecting flames, smoke sensing, heat sensing, sensing of chemical substances, analysing weather conditions, tracking, water bombing, handling the firefighting line, increasing the range of radio communication system, coordinating a swarm, cooperating with robots and/or other UAV, and delivering relatively small devices and equipment to wildfire responders.

Figure 27 demonstrates a UAV above firefighting vehicles in the woods in a wild-fire scenario.

Figure 27. UAV above firefighting vehicles in the woods in a wildfire scenario

Source: (Fotokie, 2022)

An overview of selected systems for real-time wireless video transmission from a UAV is presented in Figure 28.

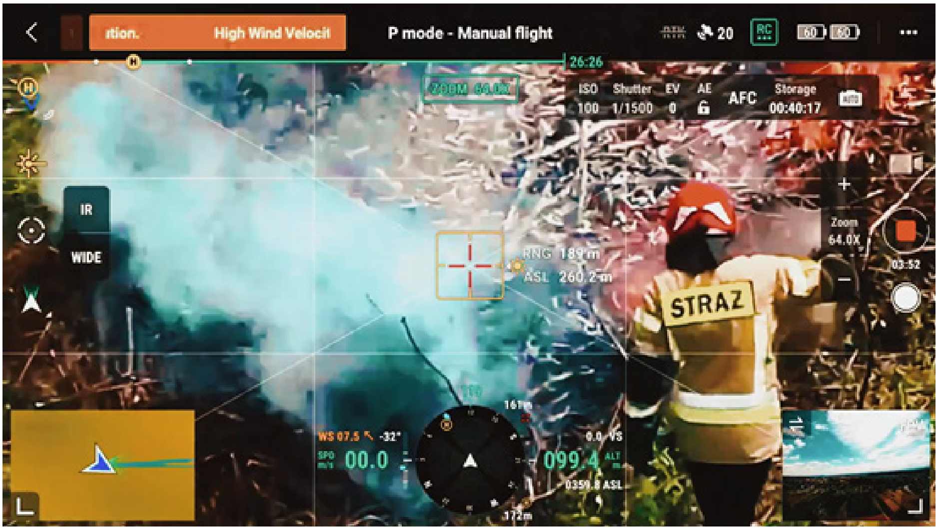


Figure 28. Overview of selected systems for real-time wireless video transmission from UAVs. On the left – Mobile Command Centre (RPASAR), on the right – ACO Streamer 4K LTEA (ACO Solutions)

Source: (Youtube, 2022; Fellner, 2023)

UAVs are really universal tools that may be deployed for all wildfire management phases. It means not only their usefulness for preparation and pre-planning activities (phase A), but also in direct response (phase B), and reconstruction and recovery (phase C). The general view on possibilities of using UAVs is presented in Table 25. Relationships with particular phases of wildfire management are described. The relationships consider the basic drone functionality and as well as functionalities that are determined by devices integrated in a UAV. It should also be added that data and information compiled by a drone can be transmitted to other devices and communication systems to feed computational tools, decision support systems or just to complete the situational picture.

Table 25. UAVs and wildfire management phases

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase A *(preparation and preparedness)*	Compiling information about the wildfire scene and relevant conditions (terrain conditions, weather conditions, etc.). Reconnaissance activities. Analysing the potential secondary threats to a fire. Preparing alternative extinguishing methods. Enhancing abilities of communication systems. Analysing arrival possibilities. Facilitating the organisation of wildfire scene (marking defence lines, points of concentration for resources of wildfire responders, etc.). Raising situational awareness.
Phase B *(response)*	Identifying wildfire manifestations (flames, smoke, heat). Identifying secondary threats (secondary fires, damages in critical infrastructure). Monitoring the firefighting action. Analysing the evacuation needs and possibilities. Extinguishing a fire. Raising situational awareness.
Phase C *(reconstruction and recovery)*	Effectiveness of monitoring of the reconstruction and recovery processes. Notifying of threats to reconstruction and recovery.

Source: own study

The most visible operational potential of drones seems to be connected with the second phase of wildfire management, and namely wildfire response. Consequently, training activities should reflect drone functionalities to directly support wildfire responders (firefighters, forest services, etc.) in their specific activities. However, a complex set of relationships is noticed directly in the preparation and preparedness phase. This also affects training possibilities as it is hard to imagine training about drones without their direct use. Serious organisational and merit-related consequences are generated for the training organiser and attendees in this case. The consequences concern training objectives, scope, forms, methods and materials.

The construction, the operational procedure and functionalities of a drone affect the training for wildfire response. As regards technology analysis and demonstrations (pilots) organised during the SILVANUS project, the following training guidelines can be enumerated:

1) The use of drones during a training may help match training objectives related to raising situational awareness, detecting wildfire manifestations, analysing hazard development, fire risk assessment, optimising the distribution of resources, extinguishing action, and field reconnaissance activities.
2) The reference training scope can cover raising the situational awareness, effective delivery of resources to the wildfire scene, risk communication, risk assessment, crisis communication, and cooperation between firefighting actors.
3) A general description of the tool functionalities can be outlined during lectures, talk, discussion and technology presentation. A significant part of a training course needs to be focused on self-operating of a drone in the woods. Practical exercises and field exercises are especially desirable. The attendee must be able to use a drone in practice (when training drone operators) or to use data/information compiled by a drone for the wildfire response purposes. When a drone is used to deliver information input to computational processes, the participant should know how to properly collect interesting information and provide input to relevant tools and decision support systems.
4) They following training materials are recommended to achieve training goals with the use of a drone:
    a) general technology leaflet,
    b) drone operational manual,

c) operational procedures (in ‘step-by-step’ formula),
d) description of an analysis procedure (in the ‘step-by-step’ formula),
e) procedure of data transfer from a drone to other devices and/or systems.

5) The direct presence of the technology provider is not mandatory, because access to drone operators and drone trainers is common. Good preparation of training materials is crucial from the viewpoint of time constraints. It should ensure merit-related preparation of trainees before a training session to organise it effectively.

Robots (which are also called ‘ground robots’, ‘unmanned ground vehicles’, UGV, ‘ground vehicles’) are gaining in importance for disaster risk reduction (DRR) (Xu, Xue, 2023; Shaw, Kishore, 2023). Their development has been a technological trend for many years. Current safety and security conditions are determining the developments in a number of disaster-related directions (Sakurai, Shaw, 2021). Wildfire response seems to be prospective. Even if robots are not commonly used in response nowadays, new construction, technical performance and areas of implementation shed light into their deployment for preparation and pre-planning activities, including training.

Some of the functionalities of robots correspond to those of humanitarian drones. They include transport and delivery capabilities, surveying and monitoring capabilities, and communication and integration capabilities (Rejeb et al., 2021). A robot as such is a kind of a platform. This limits its abilities to deliver some relatively light items. When additional devices are deployed to a robot, its abilities increase. In accordance with preparation and pre-planning activities for wildfire response, special attention should be paid to cameras, video cameras, sensors, communication devices, demineralisation equipment, firefighting post and other firefighting equipment, equipment to collect samples, evacuation devices, etc. This means high technology integration potential with a positive impact on enhancing possibilities to support or even replace responders in conducting dangerous activities and tasks that require physical strength.

Figure 29 presents a robot integrated with a smoke detector, LIDAR and geo-localiser.

Figure 29. Robot integrated with a smoke detector, LIDAR and a geo-localiser

Source: own resources

Robots are deployable to activities that characterise all phases of wildfire management. They may facilitate the preparation for wildfire response (phase A), direct support in operational activities in case of a fire outbreak (phase B), and creating operational capacities to investigate the post-fire scene in accordance to reconstruction and recovery activities (phase C). Table 26 lists relationships of robots use with particular phases. Likewise to drones, the relationships refer to basic robot functionalities as well as functionalities determined by devices integrated to a robot. It should be added that data and information compiled by a robot device can be transmitted to other devices and communication systems to feed computational tools, decision support systems or just to complete situational picture. Robots may also support the use of drones, playing a role of a charging device.

Table 26. Robots and wildfire management phases

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase A *(preparation and preparedness)*	Compiling information about the wildfire scene and relevant conditions (terrain conditions, weather conditions, etc.). Reconnaissance activities (the ground perspective). Analysing potential secondary threats to a fire. Preparing alternative extinguishing manners (for example quasi-mobile extinguishing posts). Enhancing abilities of communication systems. Investigating arrival roads. Facilitating the organisation of the wildfire scene (marking of defence lines). Raising situational awareness.
Phase B *(response)*	Identifying wildfire manifestations (flames, smoke, heat). Identifying secondary threats (secondary fires, damages in critical infrastructure). Delivering equipment. Evacuating people, animals and equipment. Ad hoc enhancing communication abilities in the woods. Putting out a fire. Raising situational awareness.
Phase C *(reconstruction and recovery)*	Investigating the post-fire scene. Collecting samples in the post-fire scene. Monitoring of reconstruction and recovery processes. Notifying of threats to reconstruction and recovery.

Source: own study

As far as current technological abilities are concerned, robots may be valuable tools to provide support in phase A (preparation and preparedness) and phase C (reconstruction and recovery). From the practical point of view, its implementation in phase B (response) is limited because of the relatively low speed of the vehicle and poor resistance to fire manifestations (especially flames and thermal radiation). These issues need to be taken into account when planning and delivering a training course.

Construction, operational procedure and functionalities of a robot are used in training for wildfire response. Technology analyses and demonstrations (pilots) carried out during the SILVANUS project allow formulating the following training guidelines:

1) The use of a robot during a training course can serve as support in facing training objectives related to raising situational awareness, detecting wildfire manifestations, analysing hazard development, fire risk assessment, investigating the wildfire scene (from the ground perspective which may be different than the one from the air), extinguishing actions and field reconnaissance activities.
2) The reference training scope can take into consideration the raising of situational awareness, effective delivery of resources to the wildfire scene, emergency evacuation, risk communication, risk assessment, crisis communication, firefighting action, and collecting samples.
3) A general description of the tool functionalities can be done during lecture, talk, or discussion. Technology presentation before the practical part of a training course is definitely required. A significant part of training needs to be focused on the use of a robot in the woods. Practical exercises, field exercises and technology tests are desirable. Attendees must be aware of robot abilities and constraints. When a robot is used to deliver information input to computational processes, the attendee should know how to properly collect interesting information and feed relevant tools and decision support systems.
4) The following training materials are recommended to achieve training goals with the use of a robot:
   a) general technology leaflet,
   b) robot operational manual,
   c) a manual on robot integration with other technologies,
   d) operational procedures (in the ‘step-by-step’ formula),
   e) description of the analysis procedure (in the ‘step-by-step’ formula),
   f) procedure of data transfer from a robot to other devices and/or systems.
5) The direct presence of the technology provider is mandatory, as access to robot operators and robot trainers is significantly limited. Training materials should be properly prepared and shared among participants before a training course to organise the training session effectively and without the necessity of describing and discussing basic issues.

The forward command centre means an ad hoc unit of response organisation established to support decision makers (commanders, action staff, analysts, emergency managers, disaster managers, crisis managers, etc.) on the fire scene or near the fire scene. The main idea is to shorten the time between making decisions and carrying out response activities, enhancing situational awareness, and simplifying the use of new technologies. There are many different standards for organising a forward command centre in accordance with the operational context, situational forecast, cooperating entities, and technologies used (Clark et al., 2011). In addition, there may be differences in the centre's organisational assumptions and good practices in a given country due to differences in field conditions, fire protection systems, disaster management systems, etc.

From the functional point of view, a forward command centre is to enhance situational awareness, improve communication, upgrade coordination, centralise resource management, and streamline incident tracking and documentation. It may be also used directly for the purposes of training and preparedness (Belanger, 2023). The centre has an organisational and technological potential to integrate multiple tools and solutions (organisational ones and technical ones) to support wildfire response. This can be reflected in preparation and pre-planning activities focused on technical and functional integrating to different data sources, collecting multiple kinds of data, analysing data, and then forming the situational picture. The activities may also concern devising response strategies, supporting decision makers, and delivering information (including orders) to a commander and field responders. The potential of the centre is noticeable in terms of possibilities to structuring communication, ensuring communication channels, and ensuring continuity of communication regardless of the impeding issues. The forward command centre may significantly facilitate coordination between firefighting actors, optimising resource deployment as well as defining the computational infrastructure to monitor, analyse and foresee wildfire conditions.

Figure 30 presents the placement of forward command centre in the overall information management process related to the use of SILVANUS technologies. It reflects in particular its placement in the overall wildfire response.

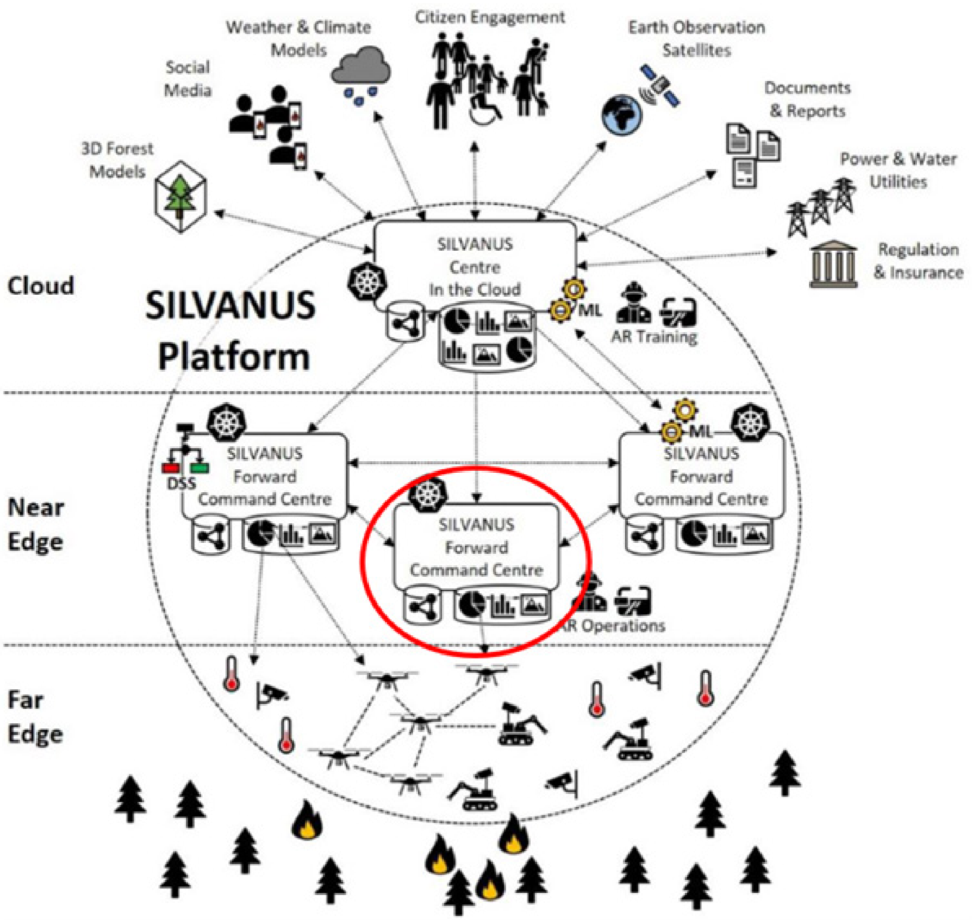


Figure 30. Placement of the forward command centre in the overall information management process related to the use of SILVANUS technologies

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

Even if the forward command centre is a formula that may be applied in all wildfire management phases, it seems to be the most valuable after the outbreak of a fire (the response phase). Nevertheless, it is forward-looking solution that aims to streamline preparation and pre-planning activities by adjusting them to the response rigours, and support first reconstruction and recovery activities (to be carried out immediately after a fire is extinguished). Table 26 lists relationships identified between the use of the forward command centre and particular phases of wildfire management (phase A, phase B, and phase C).

Table 27. Forward command centre and wildfire management phases

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase A *(preparation and preparedness)*	Compiling information about the wildfire scene and relevant conditions (terrain conditions, weather conditions, etc.). Analysing preliminary and secondary threats to a fire. Optimising the localisation and compensation of resources. Determination and enhancing abilities of the communication systems. Facilitating the organisation of the potential wildfire scene (by determining the communication hub). Raising situational awareness.
Phase B *(response)*	Analysing the response action and raising its effectiveness. Enhancing abilities of the communication systems. Facilitating the organisation of the potential wildfire scene (by defining a communication hub). Raising situational awareness.
Phase C *(reconstruction and recovery)*	Monitoring the reconstruction and recovery processes. Notifying threats to reconstruction and recovery.

Source: own study

The deployment method of the forward command centre depends on the wildfire management phase. As it is focused on the preparation and pre-planning activities for wildfire response (phase A), the centre can be used physically (near the probable wildfire scene) or non-physically (in the computational and communication cloud). The two options are also feasible concurrently. The flexible formula of the forward command centre allows achieving numerous configurations of tools, devices, and, consequently, functionalities. This sheds light on the huge training potential of this solution.

The specifics of the centre formula and its potential to integrate multiple technologies are advantages for preparing and pre-planning the wildfire response. The technology analysis and demonstrations (pilots) conducted during the SILVANUS project provide a background to formulate the following training guidelines:

1) The use of the forward command centre during a training course can provide support in facing training objectives related to raising situational awareness, analysing hazard development, fire risk assessment, investigating the wildfire scene, monitoring the effectiveness of wildfire response, and determination of the cooperation network.
2) The reference training scope can take into consideration raising of situational awareness, immediate dispatch of wildfire responders, effective delivery of resources to a wildfire scene, comprehensive reconnaissance of the hazard situation, risk communication, risk assessment, crisis communication, firefighting action (including firefighting tactics), and cooperation between firefighting actors.
3) The general description of the centre can be outlined during the lecture and talk. Manual presentation of the centre functionalities before the practical part of a training course is necessary. A significant part of the training needs to be focused on launching the centre and its use in achieving the wildfire response goals. Practical exercises and field exercises are recommended. The attendee must be able to play different roles in the centre and/or make use of its functionalities to carry out response activities.
4) The following training materials are recommended to achieve training goals with the use of the forward command centre:
   a) a map of centre functionalities,
   b) procedures on how to use particular centre functionalities (in the 'step-by-step' formula),
   c) leaflets related to technologies integrated in the form of forward command centre,
   d) safety guidelines,
   e) description of firefighting tactics,
   f) descriptions of the local emergency management system, disaster management system, and/or crisis management system.
5) The direct presence of the technology provider is not mandatory if the centre functionalities are intuitive and correspond directly with the operational needs of wildfire responders. However, technical complexity of the centre could require access to technical staff to support attendees when necessary.

MESH-in-the-Sky is the original name of a communication solution to ensure communication in severe conditions in a forest. Classical communication tools and systems may be insufficient to connect field responders with commanders and other responders and cooperating entities due to unevenness of the terrain, long distances, or other factors hindering communication (for example infrastructure localised in a forest, high trees, limited range of radio waves and GSM, high cost of satellite communication, communication shielding or cross-polarisation effects (Popov, 2019).

MESH-in-the-Sky is an example of an effective mesh network technology. It is developed in the SILVANUS project and “(…) designed to establish robust wireless communication for first responders during critical fire operations in the forest. 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).

The general idea of MESH-in-the-Sky is presented in Figure 31. It expresses the network character of this solution and the approach to ways of ensuring communication abilities appropriate to challenging terrain conditions in the woods.

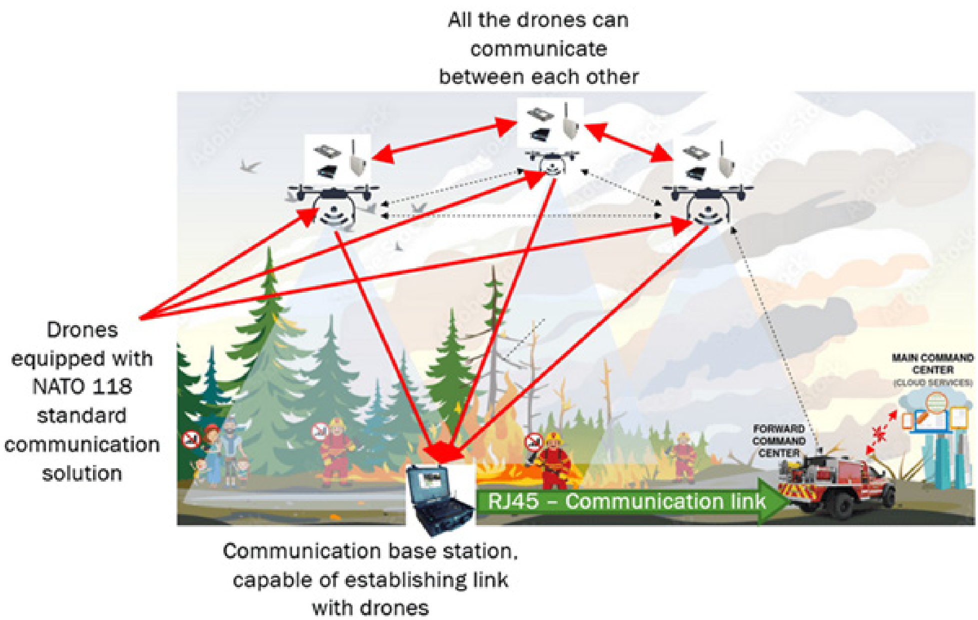


Figure 31. General concept of MESH-in-the-Sky

Source: (SILVANUS, 2024)

MESH-in-the-Sky is a forward-looking solution when effective communication is needed. As the communication plays crucial role for information exchange in the woods, the tool has found its use. In accordance with its specifics, this network may provide support for the execution of activities that characterise all wildfire management phases. Relationships identified between the use of this tool and particular phases of wildfire management are presented in Table 28.

Table 28. MESH-in-the-Sky and wildfire management phases

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase A *(preparation and preparedness)*	Establishing communication network in the woods. Transferring data. Raising situational awareness.
Phase B *(response)*	Establishing communication network in the woods. Enhancing abilities of communication systems. Transferring data. Raising situational awareness.
Phase C *(reconstruction and recovery)*	Establishing communication network in the woods. Raising situational awareness.

Source: own study

Although MESH-in-the-Sky is characterised by a relatively small number of relationships to wildfire management phases, their significance is worth to be emphasized. Lacks in communication are unacceptable from the viewpoint of wildfire response effectiveness and may even pose a direct danger to human life and health. Almost every response activity is somehow related to communication processes. This highlights the necessity of establishing and maintaining an efficient communication network and also justifies the use of MESH-in-the-Sky in practice. Special attention needs to be placed on the preparation and pre-planning activities, including training. It is essential to ensure that the network will operate correctly and play its important role.

The MESH-in-the-Sky can be used in training processes when preparing and pre-planning for wildfire response. Technology analyses and demonstrations (pilots) conducted during the SILVANUS project allow the following training guidelines to be formulated on how to use the network in a way that maximises the educational effect:

1) The use of MESH-in-the-Sky during training can provide support in facing training objectives related to making situational awareness, data transfer, risk communication, crisis communication, and determination of the cooperation network.
2) The reference training scope can take into consideration raising situational awareness, immediate dispatch of wildfire responders, effective delivery of resources to a wildfire scene, comprehensive reconnaissance of the hazard situation, providing input to computational tools and decision support systems, risk communication, risk assessment, crisis communication, and cooperation between firefighting actors.
3) A general description of functionalities of the tool can be done during lecture and talk. Specific areas of the tool use can be analysed during case studies and implementing of the classical problem method. An essential part of a training course needs to be focused on launching MESH-in-the-Sky in the woods. It is necessary to take into account training scenarios related to typical communication constraints. The attendee must be able to face these constraints.
4) The following training materials are recommended to achieve training goals with the use of MESH-in-the-Sky:
   a) communication map (senders, receivers and relationships between them),
   b) technical communication structure (integrated devices),
   c) procedures on ways of using MESH-in-the-Sky to achieve particular communication goals (in the ‘step-by-step’ formula),
   d) leaflets related to technologies integrated in the form of the mesh,
   e) safety guidelines,
   f) descriptions of the local emergency management system, disaster management system, and/or crisis management system.
5) The direct presence of technology provider is required. Training materials should be distributed to attendees before commencement of a training session. In addition, the technical complexity of the mesh requires access to technical staff to support attendees when necessary.

End-technologies seem to be the most tangible tools and solutions for training participants. Their use is often related to manual activities and field forms and methods of training (practical exercises, field exercises, technology presentations). This determines specific safety requirements, which should be met during a training course and reflect technical aspects of the tools and severe terrain conditions in the woods. The integratory role of some of them should be highlighted. This means that some of end-technologies can determine platforms (physical platforms or non-physical platforms in the cloud) for other technologies, increasing abilities to enhance preparation and pre-planning activities for wildfire response.

4.4. Functionalities of decision support system

In the analysed context, the decision support system is understood as computational, analytical and optimisation IT environment to support decision support processes and facilitate making decisions on wildfire response. It allows implementation of spatial modelling, multiple optimisations, multi-criteria decision analyses, deploying the graph theory, simulations, text mining, and combined modelling (Elkady et al., 2024). The decision making formula is quite flexible and the system functionalities depend on algorithms and data/information uploaded. This enables the integration of decision support systems to sensing and monitoring technologies as sensor readings and other data/information feed these systems.

The decision support system is one of the main outputs of the SILVANUS project. The project delivers a complex set of system functionalities, which may be useful in preparation and pre-planning activities for wildfire response. They are as follows (SILVANUS, 2024):

1) Resource allocation of response teams.
2) Health impact assessment.
3) Evacuation route planning.
4) Continuous monitoring of rehabilitation strategy index.
5) Ecological resilience index.
6) Biodiversity index calculation.
7) Soil erosion index.
8) Integrated data insights.
9) Forest fire alert system.
10) Priority resource allocation.
11) Deep learning model for wildfire severity prediction.

Resource allocation of response teams is intended to facilitate response planning on the basis of resource allocation in terms of a wildfire risk. This functionality "(…) is to assist commanders in taking 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 to assign additional teams to a specific area that is at high-risk" (SILVANUS, 2024).

This solution considers such input information, as fire detection results, initial unit distribution, fire spread projection, distribution of the population in the danger zone and GIS data. It optimises the location of response teams on the basis of a mathematical model. The model makes optimisation result concerning minimisation of the number of people that may be exposed to risk (and above all life loss) in the high-risk areas (the first, higher optimisation requirement), and minimisation of the total cost of fire containment and property losses (the second, lower optimisation requirement).

Figure 32 presents a view of results of resource allocation of response teams in the SILVANUS decision support system.

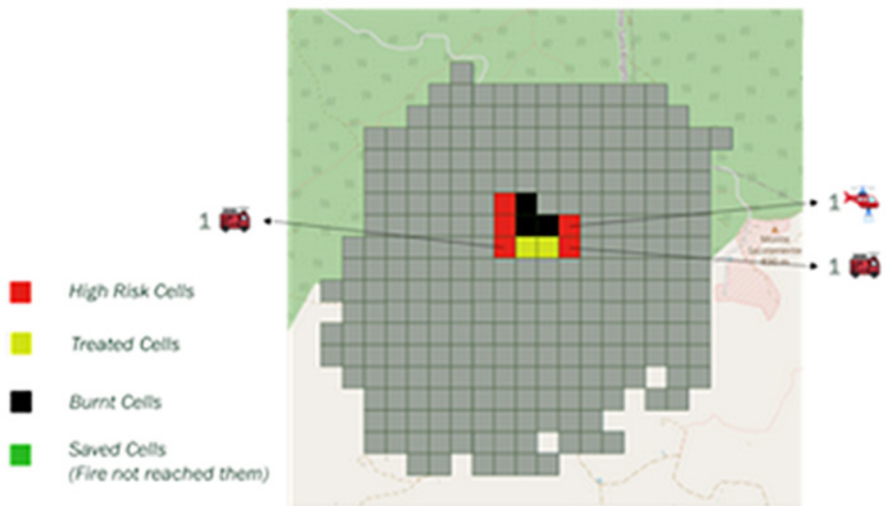


Figure 32. Results of the use of resource allocation of response teams in the SILVANUS decision support system

Source: (SILVANUS, 2024)

The **Health impact assessment** functionality allows analysing wildfire indicators regarding the prediction of health consequences for people in danger. It "(…) reflects the potential impact of wildfire emissions on air quality and health of firefighters, first responders and nearby citizens" and considers "(…) local air quality surrounding the fire incident by adhering to the European Air Quality Index standards and offers health recommendations both to general and sensitive populations" (SILVANUS, 2024).

As regards the health impact assessment functionality, multiple mobile and stationary IoT devices are connected. They compile data on concentrations of harmful emissions. Special attention is placed on particulate matter of a diameter of 2.5 µm – $PM_{2.5}$, particulate matter of a diameter of 10 µm – PM_{10}, ozone – O_3, nitrogen dioxide – NO_2, and sulphur dioxide – SO_2. Measurement results can be transferred to computational models for further analysis or just serve for simple comparisons of wildfire emissions with health standards, regulations and good practices.

Evacuation route planning is intended to analyse evacuation conditions and suggest proper evacuation routes when planning wildfire response. This functionality corresponds to issues that are particularly of importance when considering human safety and health in case of a wildfire. This is to ensure that diverse people, i.e. victims, eyewitnesses and other forest users, are not affected by hazard manifestations (flames, thermal radiation, smoke). It is also important to plan arrival routes for wildfire responders to reduce the risk of a counter flow (for example when evacuees move using the same roads as the responders and interfere with arrival to the wildfire scene).

The general approach is to collect data and set out evacuation routes. The mathematical model takes into consideration information about fuel, topography, meteorology, fire spread, air quality, and smoke dispersion. The optimisation result is geolocated and mapped to make it operational for wildfire managers and responders.

Results of the use of evacuation route planning functionality are illustrated on Figure 33.

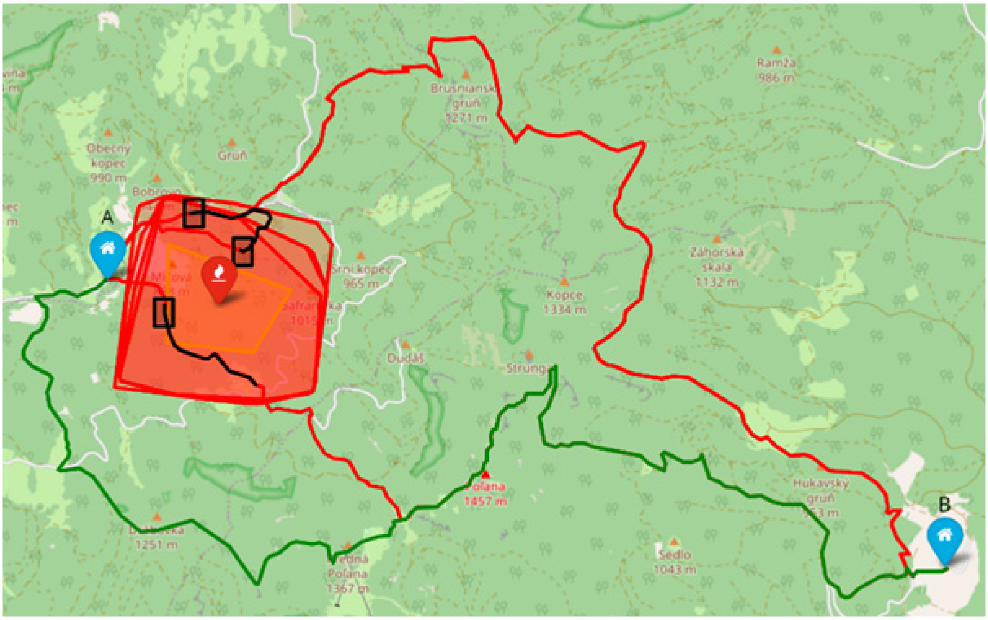


Figure 33. Results of the use of evacuation route planning functionality

Source: (SILVANUS, 2024)

The **continuous monitoring of rehabilitation strategy index** is devised to parametrise the rehabilitation strategy for the woods and to monitor relevant processes. The index allows to analyse "(…) forest conditions over time, with input from earth observation data and stakeholder entry. It provides the spatial-temporal analysis of forest conditions and the influencing factors, including societal aspects and climate changes" (SILVANUS, 2024).

When calculating the continuous monitoring of the rehabilitation strategy index, data and information on satellite images, fire incidents, rehabilitation programmes, policy and soil measurement, forest fire-related variables are respected. This allows simultaneous calculation of the Normalized Difference Vegetation index (NDVI), Forest Canopy Density (FCD), and Net Burn Ratio (NBR). They are references for further calculations of the rehabilitation strategy index but also determine relatively independent monitoring factors. Moreover, time-reference is presented, and expected values of rehabilitation effectiveness are illustrated.

Figure 34 illustrates results of continuous monitoring of rehabilitation strategy index.

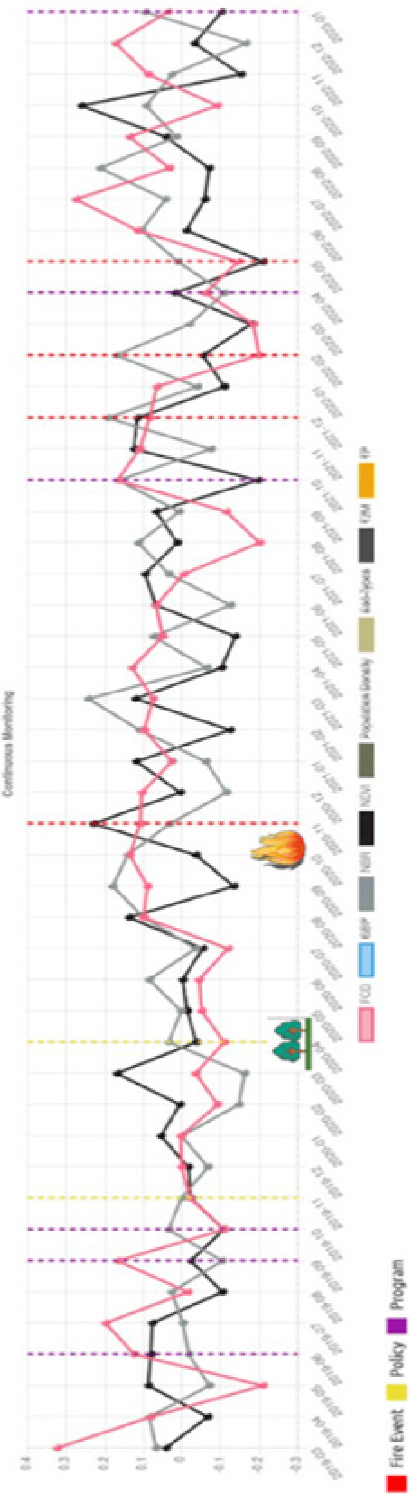


Figure 34. Results of continuous monitoring of rehabilitation strategy index

Source: (SILVANUS, 2024)

The **ecological resilience index** enables the parametrisation of 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. It refers to environmental resilience, which corresponds closely with the disaster risk reduction approach. At the highest level of generality, the index reflects such resilience aspects as disturbance magnitude, recovery magnitude, elasticity/recovery speed, and plasticity.

From the substantive point of view, the magnitude of the disturbance refers to the changes in condition in the affected area after the wildfire. The recovery magnitude means a specific duration to restore the woods in the given area to their initial state before the next wildfire incident occurs. The elasticity/recovery speed expresses the rate of recovery processes after a wildfire. And plasticity is identified with the extent of deviation from the initial state of the woods after a wildfire (SILVANUS, 2024). Relevant calculations require an information input related to fire incidents, rehabilitation programmes, policy and soil measurement.

Results of the use of ecological resilience index are visualised in Figure 35.

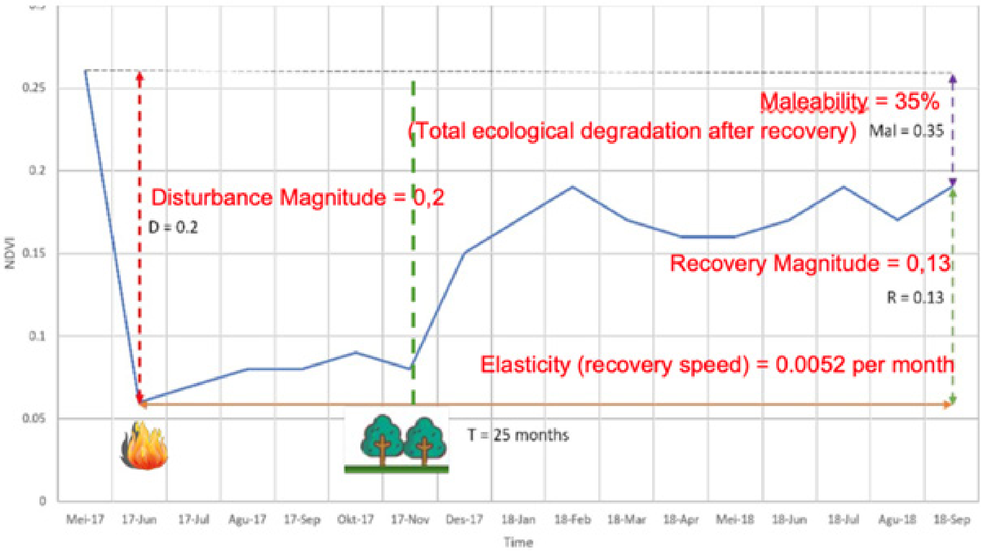


Figure 35. Results of the use of the ecological resilience index

Source: (SILVANUS, 2024)

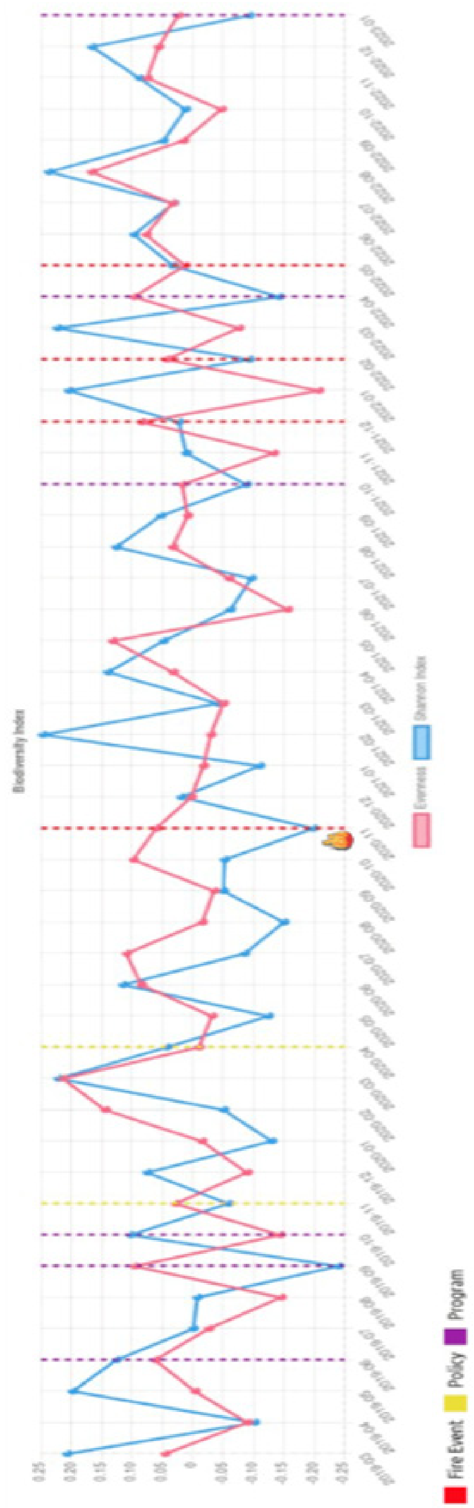


Figure 36. Results of the use of the biodiversity index calculation

Source: (SILVANUS, 2024)

Biodiversity index calculation is the next functionality of the SILVANUS decision support system. The functionality enhances situational awareness on potential fire load in the given area.

This functionality transforms satellite images and calculates the Shannon Index and Evenness Index, respecting the given time perspective and area (SILVANUS, 2024).

Figure 36 presents results of the use of the biodiversity index calculation.

In turn, the **soil erosion index** is intended to assess and predict soil erosion in the woods, paying special attention to areas impacted by wildfires. Relevant information is important to raise awareness of wildlife conditions after a disaster and may be valuable to monitor reconstruction and recovery processes. In addition, this information may constitute an input to other computational tools.

The functionality "(…) aggregates topographic data, precipitation data, and vegetation type from sources such as Digital Elevation Models (DEM), Copernicus satellite images and other environmental datasets. It transforms topographic data into critical variables, such as slope and flow path length, and utilizes precipitation data and vegetation type to assess soil erosion risk" (SILVANUS, 2024).

Integrated data insights mean the functionality intended to improve decision-making processes during wildfire emergencies by utilising the combined knowledge gained in the project. It has a substantial technology integration potential as the insight base on multiple sources of data and information compiled.

The main functional idea is to combine and analyse data from a variety of sources. These sources could include social media, IoT devices, etc. Their comparison may facilitate shaping the situational awareness among all groups of wildfire stakeholders, make risk-informed decisions, transfer guidelines reflecting proper behavioural patterns, and establish cooperation background.

Figure 37 shows an illustrative view of the SILVANUS decision support system after the use of integrated data insights.

Figure 37. Result of the use of integrated data insights

Source: (SILVANUS, 2024)

The **forest fire alert system** is an answer for the risk of 'false positives' in early warning processes when talking about wildfire response. There are several kinds of devices, tools, systems and other solutions that enable notifying a fire in the woods. Their level of integration differs in multiple cases, countries and cooperating entities. The forest fire alert system allows automation of the fire alerting processes in terms of wildfire and making early warning possible, as well as ensures acceptable level of certainty that an alert reflects a real hazard.

The system provides such output as notification of a hazard and location of a hotspot. Furthermore, it is based on data fusion. The Dada fusion relies on connecting multiple data from different data sources to compare them and/or its elements. It analyses and confirms information concerning a hazard (fire alert) and allows assessing the probability of fire event location.

The general idea of data fusion in the forest fire alert system is illustrated on Figure 38.

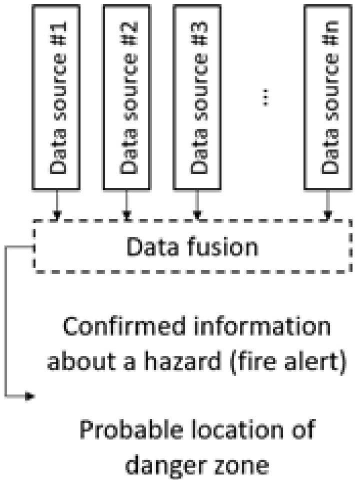


Figure 38. The general idea of data fusion in the forest fire alert system

Source: (SILVANUS, 2024)

The **priority resource allocation** functionality supports the decision making thanks to calculating wildfire probability in the given area and indicating places characterised by high priority for allocating response resources on the field.

The relevant optimisation algorithm is based on such information as the distance to settlements and roads, elevation, fuel load, historical fire, land usage, NDVI, population density, Gross Domestic Product, vegetation type, aspect, slope, temperature, and precipitation. The optimisation result is mapped and visualised. It is presented in Figure 39.

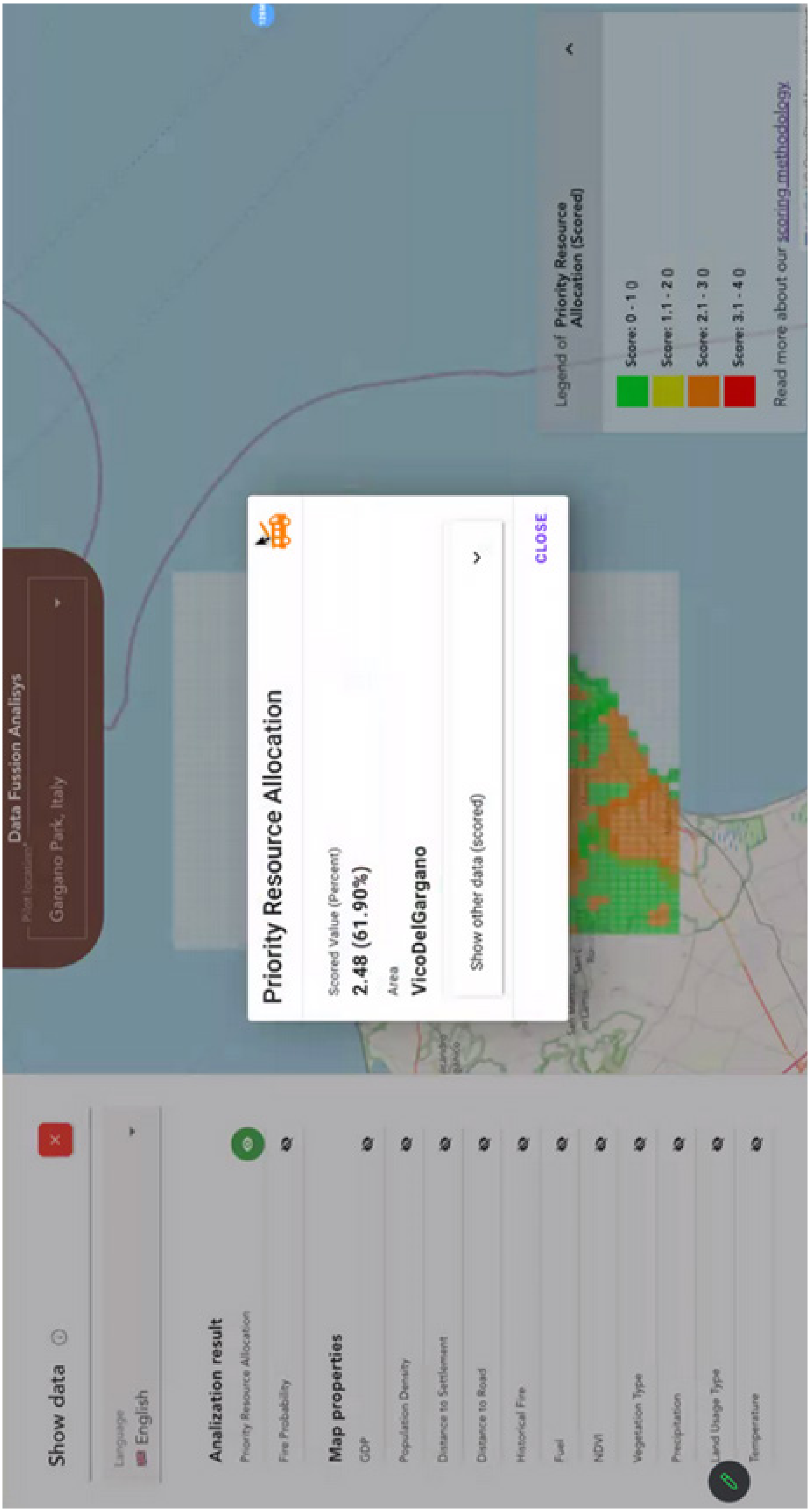


Figure 39. Results of the use of priority resource allocation

Source: (SILVANUS, 2024)

The **deep learning model for wildfire severity prediction** analyses wildfire severity scenarios on the basis of deep learning to provide input to decision-making processes. The processes can be related to preparation and pre-planning activities for wildfire response, and focused on areas that characterise the highest severity level.

The decision making process stems from deep learning and satellite data (EO-4Wildfires dataset) to predict the severity of wildfires regarding shape and size. Data initialisation is conducted to aggregate multispectral imagery, SAR data, and meteorological variables. The EO4Wildfires dataset is used to train deep learning models. Special attention is paid to significant wildfire events (SILVANUS, 2024). Specifics of the available data allows making a comparison of different regions in particular countries and entire countries.

Figure 40 presents results of the use of deep learning model for wildfire severity prediction.

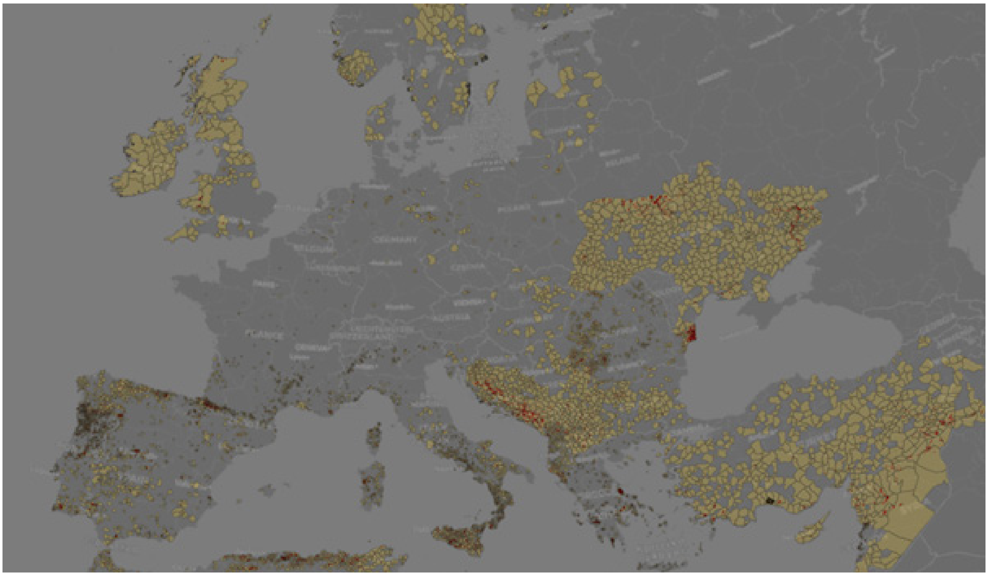


Figure 40. Results of using the deep learning model for wildfire severity prediction

Source: (SILVANUS, 2024)

The broad spectrum of functionalities offers many opportunities to use the decision support system for preparation and pre-planning activities for wildfire response. It is hard to precisely ascribe particular system functionalities to particular phases of wildfire response because some of them can be used in more than a single phase, either directly or indirectly. Despite of the above-mentioned issue, the following classification may help in understanding the general idea of implementing the decision support system to wildfire management:

1) regarding preparation and preparedness (phase A):
   a) resource allocation of response teams,
   b) health impact assessment,
   c) priority resource allocation;
   d) deep learning model for wildfire severity prediction;
2) regarding response (phase B):
   a) evacuation route planning,
   b) integrated data insights,
   c) forest fire alert system;
3) regarding reconstruction and recovery (phase C):
   a) continuous monitoring of the rehabilitation strategy index,
   b) ecological resilience index,
   c) biodiversity index calculation,
   d) soil erosion index.

Even if some of the functionalities can address also other phases of wildfire response, their classification is helpful in identifying relationships between them and the phases. Table 29 presents the reference list of relationships.

Table 29. Decision support system functionalities and wildfire management phases

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase A *(preparation and preparedness)*	Allocating response teams according to wildfire risk. Indicating priorities in resource allocation regarding wildfire risk and relevant determinants. Assessing health impact of a wildfire. Tailoring preparation and pre-planning activities to predicted wildfire severity. Adjusting the preliminary tactical assumptions and resource compensation to current and simulated situational conditions.

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase B *(response)*	Confirming the occurrence of a hazard. Setting out the danger zone. Analysing and predicting wildfire development. Adjusting resource compensation and distribution to current and predicted conditions of a wildfire. Planning the evacuation route. Optimising arrival routes to the wildfire scene. Communication risks to stakeholders.
Phase C *(reconstruction and recovery)*	Monitoring the effectiveness of the rehabilitation strategy. Analysing the ecological resilience index in the given time perspective and the given area. Calculating biodiversity aspects in the given time perspective and the given area. Analysing soil erosion in the given time perspective and the given area. Informing of and optimising reconstruction and recovery processes.

Source: own study

All of these relationships can be reflected in training to prepare and pre-plan for wildfire response (also taking into account activities to be conducted after a fire is extinguished). It should be emphasized that the decision support system can integrate particular functionalities and provide in-depth analytical possibilities to meet training objectives. It may cross-cut all phases of wildfire response and transform the educational process to cover all phases of wildfire management.

The decision support system can be described and used in training for wildfire response. This is an IT system and its form determines training preparation and providing. As regards technology analysis and demonstrations (pilots) organised during the SILVANUS project, the following training guidelines can be listed to allow achieving this goal efficiently and with positive impact on the educational effect:

1) The decision support system can provide support in matching training objectives related to almost of aspects of wildfire response. This can prove to be especially useful in raising situational awareness, setting out vulnerable parts of the given area (parts characterised by a relatively high fire

load), analysing the hazard development, fire risk assessment, optimising the compensation and distribution of resources, and optimising decisions on firefighting tactics.

2) The reference training scope can cover raising situational awareness, early detection and communication of a hazard, dispatch and effective delivery of resources to a wildfire scene, risk communication, risk assessment, firefighting tactics, and cooperation between firefighting actors. It is worth adding the general optimising of decisions on the basis of data and information collected.
3) The general description of tool functionalities can be provided via lecture, talk, discussion and technology presentation. A significant part of a training course needs to be focused on self-operating of the system (at least one of its functionalities). System functionalities used during a training should reflect real decision-making difficulties. Practical exercises are especially desirable. The attendee must be capable of using proper system functionalities in practice – to get proper information to make the right decision.
4) The following training materials are recommended to achieve training goals with the use of the Biodiversity profile mobile app:
   a) general technology leaflet,
   b) descriptions of system functionalities,
   c) protocols on how to use particular system functionalities (in the 'step-by-step' formula),
   d) book with case studies,
   e) description of the analysis procedure (in the 'step-by-step' formula).
5) The direct presence of technology provider is desirable but not mandatory in case of the use of simple system functionalities. If more and/or complex functionalities are expected to support a training course, the technology provider may significantly simplify the training process. Good preparation of training materials is required.

The decision support system is a powerful tool to prepare and pre-plan activities for wildfire response, especially during training. As a rule, the attendee needs to know what abilities are accessible in the system and how to use them to solve specific decision problems related to a wildfire. It is good practice to integrate wildfire-related decision support systems with such systems implemented by local/regional/state-level responders (for example fire service, forest service, public administration). This may reduce technological and manual stress as well as prove that the system has a direct influence on the response activities. Another important issue is to ensure that results of the use of decision support system functionalities are visible, mapped, illustrated, etc. This is crucial in creating a common situational picture and sharing it with multiple stakeholders. All these issues should be taken into account during training. What is more, the training can be used to validate decision making systems designed to support wildfire response.

4.5. Societal involvement tools

Public engagement is becoming increasingly important in relation to safety and security issues.. It seems to be a consequence of raising awareness that an individual is not only an object affected by hazards (including a wildfire) but also has greater or smaller influence on facing negatively perceived factors. Societal involvement tools are solutions that refer to this phenomenon. They may be used by multiple groups of wildfire stakeholders – responders, citizens, and emergency/disaster/crisis managers. This emphasises that response to a wildfire should be and can be a common issue, with positive leveraging the response potential. Consequently, societal involvement tools may be applied in preparation and pre-planning activities in the context under consideration.

The SILVANUS project delivers three kinds of tools that may be identified with societal involvement. They are as follows (SILVANUS, 2024):

1) Augmented reality / virtual reality training for firefighters.
2) Citizen engagement mobile app.
3) SILVANUS dashboard.

The **augmented reality (AR) / virtual reality (VR) training for firefighters** is an example of societal engagement tool dedicated to primary responders. Specific technology allows creating a virtual world (in case of VR) or a quasi-virtual one (regarding to AR) to conduct operational activities specific for wildfire response. The core activities concern reconnaissance and firefighting action.

The AR/VR technology allows the virtual presentation of:

a) wildfire scene (i.a. general terrain conditions, natural obstacles, reservoirs and watercourses, tree species and relevant density),
b) time of day,
c) forest roads,
d) places of resource concentration,
e) weather conditions (i.a. wind direction and force, precipitation, insolation),

f) wildfire phenomenon (i.a. flame intensity and high, extent of the flames zone and the smoke zone, smoke intensity, burned materials),
g) equipment (i.a. firefighting vehicles, firefighting lines and relevant equipment necessary to put out a fire, personal protection means),
h) other elements that regulate wildfire management (i.a. high voltage lines, gas pipes).

Elements of a virtual world are intended to achieve the defined training goals. This is why the AR/VR technology is said to be a tailor-made solution.

Figure 41 contains an illustrative view of a virtual world projected by the VR tool for the purposes of firefighter training.

Figure 41. Illustrative view of a virtual world projected by the VR tool for the purposes of firefighter training

Source: (SILVANUS, 2024)

The AR/VR technology is definitely forward-looking when considering training for firefighters. From the theoretical point of view, every scenario can be designed and played. Different views on the same situational picture (from the air, from the ground, from the player viewpoint) provide additional value in raising awareness of wildfire conditions. Consequently, the tool may have a positive impact on preparation and pre-planning activities – activities related to all phases of wildfire management (phase A, phase B, and phase C). Table 30 provides a synthetic view of possibilities of using the tool in particular phases.

Table 30. AR/VR technology and wildfire management phases

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase A *(preparation and preparedness)*	Visualisation of the potential wildfire scene. Preparing firefighters to execute operational activities. Analysing secondary threats to a fire. Raising situational awareness.
Phase B *(response)*	Visualisation of potential wildfire scene. Analysing secondary threats to a fire. Raising situational awareness.
Phase C *(reconstruction and recovery)*	Visualisation of post-fire scene. Analysis conditions for reconstruction and recovery strategies.

Source: own study

The highest cognitive value related to the use of AR/VR technology is noticeable in the first phase of wildfire management. Visualisation abilities and testing fire-fighting strategies seem to be the strengths of this tool in preparation and preparedness for wildfire response. Training is the essential part of the deployment of this technology. It should reflect AR/VR specifics as well as AR/VR technology (virtual world, controllers, scenario, etc.) needed to handle training assumptions.

The specifics and functionalities of AR/VR technology shed light on its use during a training course intended to prepare and pre-plan for wildfire response. The technology analysis and demonstrations (pilots) provide foundations to suggest the following training guidelines:

1) The AR/VR technology may facilitate achieving the training objectives related to raising situational awareness, conducting firefighting activities, analysing firefighting tactics, optimising the distribution of resources, and shaping cooperation between firefighting actors.
2) The reference training scope can cover raising situational awareness, early detection, selection of equipment from vehicles, firefighting action, equipment and extinguishing agents for extinguishing wildfires, and cooperation between firefighting actors.
3) A general description of the tool can be provided via lecture, talk, discussion, and technology presentation. A significant part of a training course needs to be focused on the direct use of the AR/VR technology to achieve

the assumed training goals. Additional technology presentations may reduce manual risks for attendees – similarly as pilot games. The main part can be organised as a didactic game or decision-making training.

4) The following training materials are recommended, which may be helpful in achieving training goals with the use of AR/VR technology:
   a) general technology leaflet,
   b) description of a virtual world,
   c) map of a virtual world,
   d) technology manual,
   e) graphical procedures on how to use controllers.
5) The direct presence of the technology provider is not mandatory when an organiser ensures a group of trainers. In general, the technology requires being supported by trainers familiarised with AR/VR specifics and technical manual standards. Good preparation of training materials can be very helpful in equipping training participants with basic information on how to use the technology in practice.

The **citizen engagement mobile app** uniquely integrates participation, consultation, collaboration, empowerment and information in the line of wildfire management. The app is dedicated to people presents in the woods. It is possible to download and install it on typical mobile devices (phones, smartphones, laptops, etc.). However, an Internet connection is required.

From the functional viewpoint, the citizen engagement mobile app ensures equipping people with the technical possibility to inform wildfire responders and warn other people of a fire and relevant derivative hazards, instructing on what to do in the event of a wildfire, and establishing a communication connection between citizens and wildfire responders by technical capabilities of crisis communication and risk communication.

Figure 42 presents illustrative views of the citizen engagement app screens.

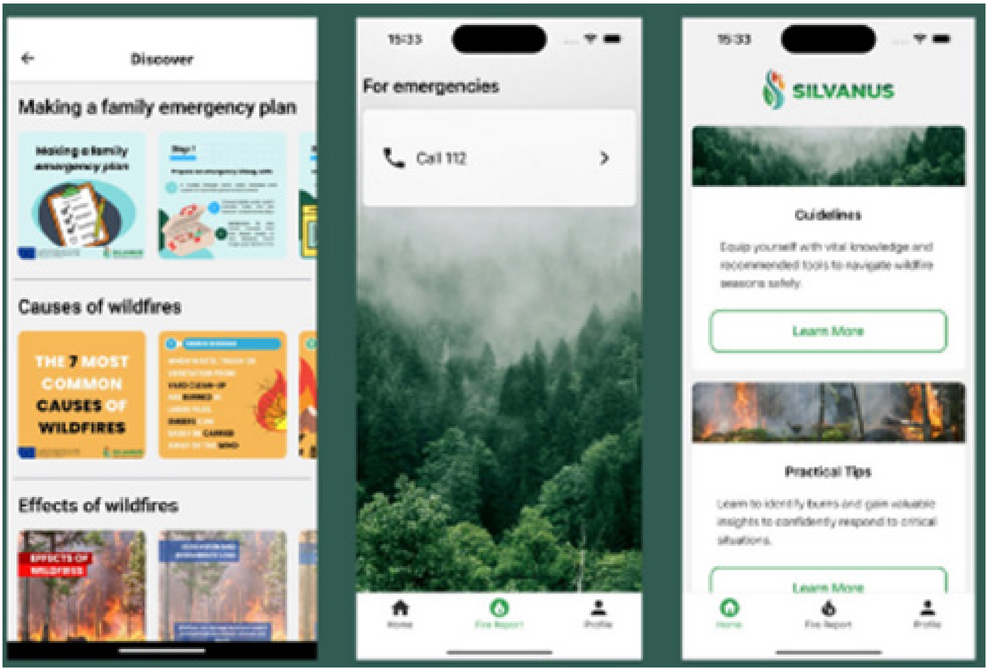


Figure 42. Illustrative views of the citizen engagement mobile app screens

Source: (SILVANUS, 2024)

Wildfire management can be supported by citizen engagement tools addressing all relevant phases – preparation and preparedness, response, and reconstruction and recovery. Table 31 presents general relationships between these tools and the phases mentioned.

Table 31. Citizen engagement mobile app and wildfire management phases

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase A *(preparation and preparedness)*	Monitoring the fire situation in the given area. Establishing communication means and methods in case of a wildfire. Educating users about proper behavioural patterns. Raising situational awareness.

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase B *(response)*	Warning about a hazard. Analysing secondary threats to a fire. Assisting users in evacuation. Raising situational awareness.
Phase C *(reconstruction and recovery)*	Educating users about proper behavioural patterns to support reconstruction and recovery activities.

Source: own study

The highest cognitive value related to citizen engagement is noticeable related to the first and the second phases of wildfire management. The possibility of communicating different information to users is crucial to make them aware of multiple wildfire management aspects. Moreover, the citizen engagement mobile app allows two-directional communication. Consequently, citizens may also send information to wildfire managers and responders to communicate issues valuable from the perspective of dealing with a fire.

The specifics and functionalities of citizen engagement mobile app determine the preparation and pre-planning activities for wildfire response – activities in the form of a training course. Technology analyses and demonstrations (pilots) allow formulating the following training guidelines:

1) The citizen engagement mobile app may facilitate achieving the assumed training objectives related to raising situational awareness, establishing ad hoc communication network that connects safety and security entities to people in a danger zone.
2) The reference training scope can cover raising situational awareness, early detection, and selection of evacuation routes.
3) The general description of the tool can be implemented via lecture, talk, discussion, and technology presentation. A significant part of training needs to be focused on the direct use of citizen engagement technology to achieve training goals. This can acquire the form of practical exercises. Attendees must be able to use the app on their own and to instruct other people on how to do it effectively (to get information necessary to proper behave in wildfire conditions).
4) The following training materials are recommended, which may prove to be helpful in achieving training goals with the use of the citizen engagement mobile app:

   a) general technology leaflet,
   b) manual procedure,
   c) procedures on how to use particular tool functionalities,
   d) scenario description,
   e) case studies.

5) The direct presence of the technology provider is not mandatory if an organiser ensures a group of trainers. In general, the technology requires to be supported by trainers familiarised with relevant specifics and technical manual standards. The devising of training materials can be very helpful in equipping training participants with basic information on how to use the technology in practice before the training session commences. The practical use of the technology during training requires preliminary defining of warnings, messages, and other information generated by the app.

The **SILVANUS dashboard** is the last example of a societal involvement tool developed in the project. It is a kind of IT dashboard (screen) intended to visualise warning, computational, analytical and optimising results obtained in the rest of SILVANUS solutions.

Figure 43 presents a view on a SILVANUS dashboard, which can be used for wildfire management purposes, including multi-entity wildfire response operations. Several layers reflect the basic functionalities to be illustrated.

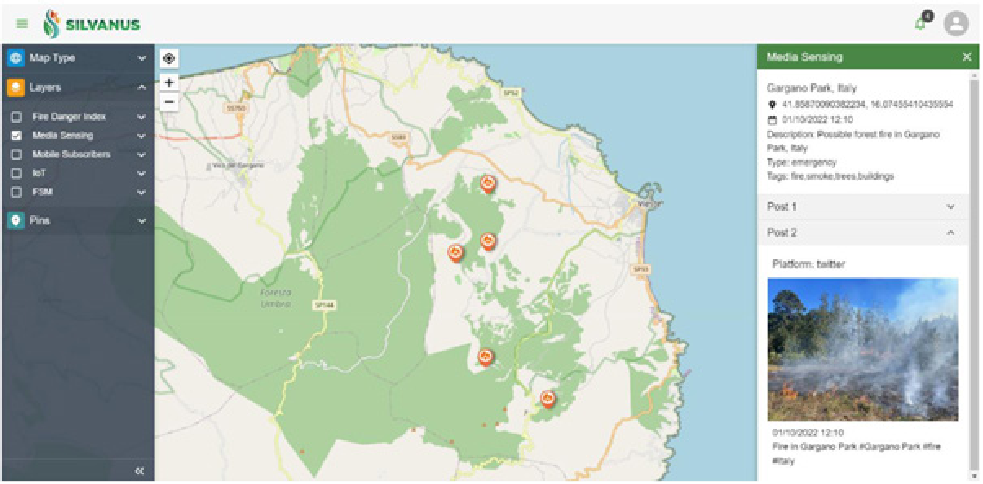


Figure 43. An example of an IT dashboard to be used for wildfire management purposes, including multi-entity wildfire response operations

Source: (SILVANUS D4.2, 2023)

As it is focused on dashboard functionalities, they depend on data collected, layers represented and solutions integrated to the tool. For example, the SILVANUS dashboard may illustrate a general map of the terrain, hot spots, the danger zone, results of the situational forecast, personal field reports, defence lines on the basis of natural and/or artificial barriers for fire, location of firefighting entities and citizens in need of help, infrastructure the presence of which in a danger zone may pose secondary threats.

The SILVANUS dashboard may be applied in all phases of wildfire management. Its specific use depends on the integrated technologies and tools. This justifies its usefulness in preparedness and readiness, response and recovery and reconstruction activities. Table 32 lists general relationships between the SILVANUS dashboard and the specified phases.

Table 32. SILVANUS dashboard and wildfire management phases

Phase of wildfire management	Reference relation to preparation and pre-planning activities for wildfire response
Phase A *(preparation and preparedness)*	Visualising the general map of a terrain. Fire weather reporting. Visualising results of calculations, analyses and optimisation (fire risk, high priority places to deploy responders, suggested evacuation roads, etc.). Raising situational awareness.
Phase B *(response)*	Visualising the general map of a terrain. Communicating warning messages and alerts. Visualising results of calculations, analyses and optimisation (fire risk, high priority places to deploy responders, suggested evacuation roads, etc.). Raising situational awareness.
Phase C *(reconstruction and recovery)*	Visualising information necessary to make informed decisions on reconstruction and recovery strategies and operations. Communicating messages and other information from post-fire scene.

Source: own study

The cognitive value related to the SILVANUS dashboard applies to all activities that may be supported by data/information visualisation. Maps play a very important role in preparation and pre-planning activities for wildfire response. Their digital forms may significantly facilitate the entire spectrum of these activities. Furthermore, screen sharing in a cloud can additionally increase this value by defining the common situational picture among all stakeholders. These strengths should be taken into account when planning and organising a training course for multiple groups of users.

The specifics and functionalities of the SILVANUS dashboard should be reflected when training is being considered. Technology analyses and demonstrations (pilots) carried out during the SILVANUS project implementation deliver practical tips on how to do it simultaneously with maximising the educational effect. Relevant guidelines are listed below:

1) The SILVANUS dashboard may facilitate achieving the entire spectrum of training objectives identified.
2) The reference training scope can cover raising situational awareness, early detection, immediate dispatch of wildfire responders, effective dispatch to wildfire scene, comprehensive reconnaissance of hazard situation, firefighting tactics, and cooperation between firefighting actors.
3) The general description of the tool can be implemented via lecture, talk, discussion and technology presentation. The presentation should consider basic functionalities and case studies on how to use them in complex scenarios. A significant part of a training course needs to be focused on the direct use of the dashboard to achieve the assumed training goals. The goals need to correspond with practical issues that determine the wildfire response. This can be done in the form of practical exercise, table top exercise, simulation, and even field exercises. Attendees must be able to use the tool on its own playing a role which refers to the attendee function in wildfire response.
4) The following training materials are recommended, which may prove to be helpful in achieving the training goals with the use of the SILVANUS dashboard:
    a) general technology leaflet,
    b) terrain map,
    c) manual procedure,
    d) procedures on how to make use of particular tool functionalities,
    e) scenario description,
    f) case studies.

5) The direct presence of the technology provider is not mandatory when an organiser ensures a group of trainers. In general, the technology requires to be supported by trainers familiarised with relevant specifics and technical manual standards (even if the dashboard is relatively intuitive in use). Devising the training materials can prove to be very helpful in providing training participants with basic information on how to use the technology in practice before a training session begins. The materials should be accessible also during a training session.

The societal involvement tools prove that practically anyone may carry out wildfire response activities. Firefighters, forest service, emergency managers, disaster managers, crisis managers and citizens are able to facilitate handling a hazard. The scope, intensity and specific involvement activities are leveraged by technological solutions used. Their complexity indicates broad possibilities in the context under consideration. As regards the societal involvement tools functionalities, activities ascribed into every phase of wildfire management may be supported. Particular attention should be placed on preparation and pre-planning activities. The tools seem to be designed especially for their purposes.

Chapter 5. New technologies in protocols of wildfire response training

5.1. Early detection and communication of the hazard

Early detection and communication of the hazard initiate wildfire response and define the first phase of the relevant process. It should proceed immediately after the outbreak of a fire to limit its consequences for the natural environment, human and animal life and health, as well as property. The detection should consider multiple sources of data and information to reduce the risk of 'false positives' and localise a hotspot precisely. It is essential to find out on what is going on and where the response is required.

Early detection and communication of the hazard give rise to specific operational needs, which should shape training objectives and scope. An in-depth analysis of the wildfire phenomenon and wildfire response standards and good practices (mentioned in section 3.5.) allow formulating the general needs that have been listed below:

a) to notify of the occurrence of a hazard,
b) to confirm the occurrence of a hazard,
c) to indicate a hazard location,
d) to share information about a hazard among stakeholders, including wildfire responders and community.

As regards the identified operational needs, technical detection, auto-detection, detection from the ground, detection from the air, conformation of the detection result, providing information about hazard to responders and the public, crisis communication, and risk communication issues should determine the deployment of relevant technologies to achieve training goals.

Training for wildfire response related to early detection and communication of the hazard applies to almost all technologies described as the reference ones in the context of preparation and pre-planning activities for wildfire response. They are presented on Figure 44.

The above-mentioned technologies ensure that the following functionalities meet operational needs and prepare trainees to perform their tasks effectively:

1) Fire detection based on social sensing – identifying the fire outbreak in social media along with supporting information (text, photos, movies, geolocation, etc.) on hazard location to cross-check with other detection solutions.
2) Fire detection from IoT devices – identifying occurrence of fire manifestations (flames, smoke, thermal radiation) in the effective detection range of IoT devices along with supporting information (geolocation of a sensor, detection direction) to cross-check with other detection solutions.
3) Fire detection at the Edge – identifying the occurrence of fire manifestations (flames, smoke) with direct location of a hazard in the forest as a cross-check manner to other detection solutions.

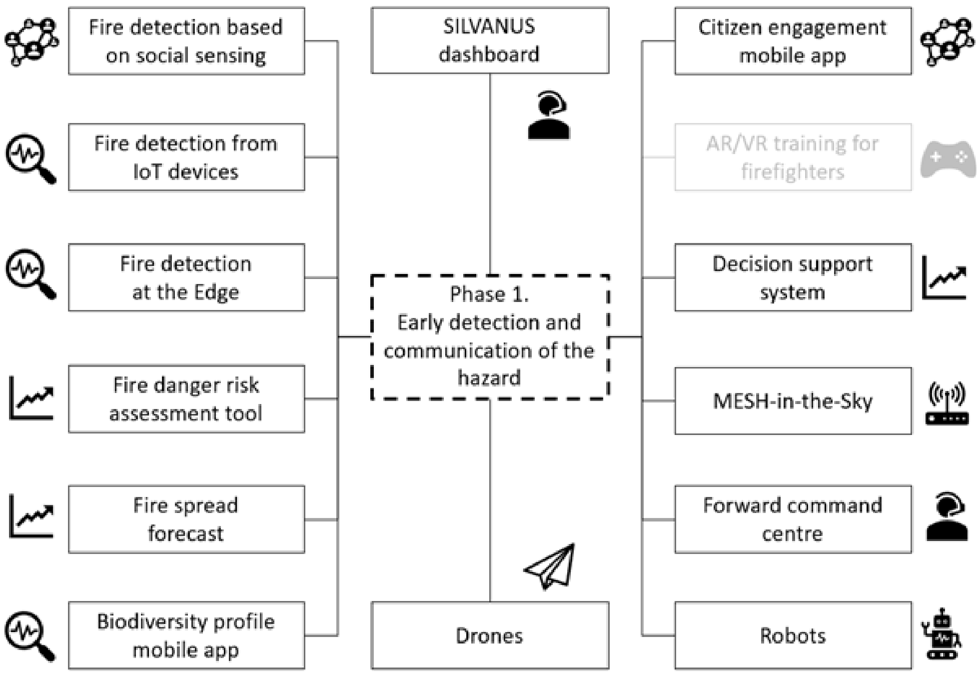


Figure 44. New technologies in protocols of wildfire response training for phase 1 – early detection and communication of the hazard

Source: own study

4) Fire danger risk assessment tool – preliminary appointment of hazard zones characterised by the highest fire risk in the given conditions to focus detection activities on those areas.
5) Fire spread forecast – simulating fire development to determine the most vulnerable areas in the woods to focus detection activities on these areas.
6) Biodiversity profile mobile app – preliminary analysis of fire load and fire vulnerability on the given area as input for risk assessment and fire spread forecast algorithms.
7) Drones – platform for multiple sensors to detect fire manifestations from the air perspective appropriately to the most vulnerable areas in the forest.
8) Robots – defining a platform for multiple sensors to detect fire manifestations from the ground perspective appropriately to the most vulnerable areas in the forest, and for charging drones to ensure longer time of their operation in the air.
9) Forward command centre – monitoring of social media, supervising detection equipment, collecting detection information, confirming the occurrence of a hazard, and communicating relevant information to stakeholders.
10) MESH-in-the-Sky – establishing an effective communication network for detection and communication processes.
11) Decision support system – appointing high-risk areas in the woods and confirming the occurrence of wildfire manifestations.
12) AR/VR training for firefighters – simulating conditions of wildfire manifestations and the first phase of wildfire response to teach checking and confirming the occurrence of a fire, and establishing the location of a hotspot.
13) Citizen engagement mobile app – communicating information about a hazard to social media.
14) SILVANUS dashboard – visualising detection results, cross-checking detection results, and determination of the location of hotspots and danger zone.

The presented technologies may shape protocols of wildfire response training regarding general functionalities that are listed below:

1) detection and warning about a hazard:
    a) fire detection based on social sensing,
    b) fire detection using IoT devices,
    c) fire detection at the Edge,

   d) fire danger risk assessment tool,
   e) drones,
   f) robots,
   g) forward command centre,
   h) MESH-in-the-Sky,
   i) decision support system,
   j) citizen engagement mobile app,
   k) SILVANUS dashboard;
2) hazard analysis and prediction:
   a) fire detection based on social sensing,
   b) fire detection at the Edge,
   c) fire danger risk assessment tool,
   d) fire spread forecast,
   e) biodiversity profile mobile app,
   f) drones,
   g) robots,
   h) forward command centre,
   i) MESH-in-the-Sky,
   j) decision support system,
   k) AR/VR training for firefighters,
   l) citizen engagement mobile app,
   m) SILVANUS dashboard;
3) in-depth analysis from the ground perspective:
   a) fire detection based on social sensing,
   b) fire detection using IoT devices,
   c) fire detection at the Edge,
   d) fire danger risk assessment tool,
   e) fire spread forecast,
   f) biodiversity profile mobile app,
   g) robots,
   h) forward command centre,
   i) MESH-in-the-Sky,
   j) decision support system,
   k) AR/VR training for firefighters,
   l) citizen engagement mobile app,
   m) SILVANUS dashboard;
4) shaping social readiness and societal behaviour:
   a) fire detection based on social sensing,

b) fire danger risk assessment tool,
c) decision support system,
d) citizen engagement mobile app.

As regards the potential of particular solutions, training for wildfire response that focuses on early detection and communication of the hazard may be organised using the example training protocol presented in Table 33.

Table 33. Exemple training protocol for early detection and communication of the hazard

No.	Training activity	Supporting technology
1	Identification of fire outbreak in the woods	IoT devices (stationary sensors installed on trees) identify the presence of smoke in the forest area Information about the identification result is visible on the SILVANUS dashboard
2	First confirmation of hazard occurrence	The SILVANUS dashboard operator uses social sensing and the citizen engagement app to analyse social media information seeking additional premises that a hazard occurred
3	Preliminary analysis of a dangerous situation	Pre-collected information about biodiversity profiles provide input to the situational picture on potential fire density in the given area The fire danger risk assessment differentiates the danger zone on the basis of risk calculation The fire spread forecast indicates the most likely scenarios for hazard development
4	Risk communication to the community	IT dashboard operator uses the citizen engagement app to communicate the hazard occurrence among the app users and sends out information on how to behave in the event of a fire

Source: own study

The reference training forms and methods in this case comprise technology presentation, practical exercises and case studies. When a training course is related to essential issues of wildfire response (firefighting activities), this protocol can serve the purposes of preliminary training sessions or a checklist to organise a training session simultaneously with table top exercises or field exercises.

The training protocol is just an example on how to combine particular technologies in a single training procedure. The technologies and their functionalities determine specific puzzle-like elements which may be integrated in several ways. These ways should be related to operational needs and, consequently, training objectives. In addition, early detection and communication of the hazard define the first phase of wildfire response to create specific training conditions. If the training scope covers also subsequent response phases, these conditions should reflect technologies used in other phases to optimise organisational efforts and highlight possibility to use the chosen technologies comprehensively.

5.2. Immediate dispatch of wildfire responders

The dispatch of wildfire responders is a rational consequence of identification of a fire outbreak in the woods. This follows early detection and communication of the hazard and defines the second phase of wildfire response. As time is crucial when considering a wildfire, the dispatch needs to be as urgent as possible. Moreover, resources dispatched to the action scene should be qualitatively and quantitatively adequate to wildfire conditions to ensure the effectiveness of firefighting action and other activities aimed at extinguishing the fire and protecting against negatively perceived wildfire consequences. This requires executing the dispatch in the optimal way possible.

The immediate dispatch of wildfire responders applies to specific operational needs which, as a rule, determine the training objectives and scope. An in-depth analysis of the wildfire phenomenon and wildfire response standards and good practices (as mentioned in section 3.5.) allows indicating the general needs that are specified below:

a) to indicate the location danger zone,
b) to appoint resources that are quantitatively prepared to the response,
c) to launch support forces (if necessary),
d) to effectively alert the appointed responders.

As regards the identified operational needs, initiating the organisation of response, the dispatch of services, information exchange and resource optimisation should determine the use of relevant technologies to achieve training goals.

The specifics of a training course for wildfire response regarding immediate dispatch of wildfire responders strongly limits the number of wildfire-related technological solutions that may facilitate specific activities. This is presented on Figure 45.

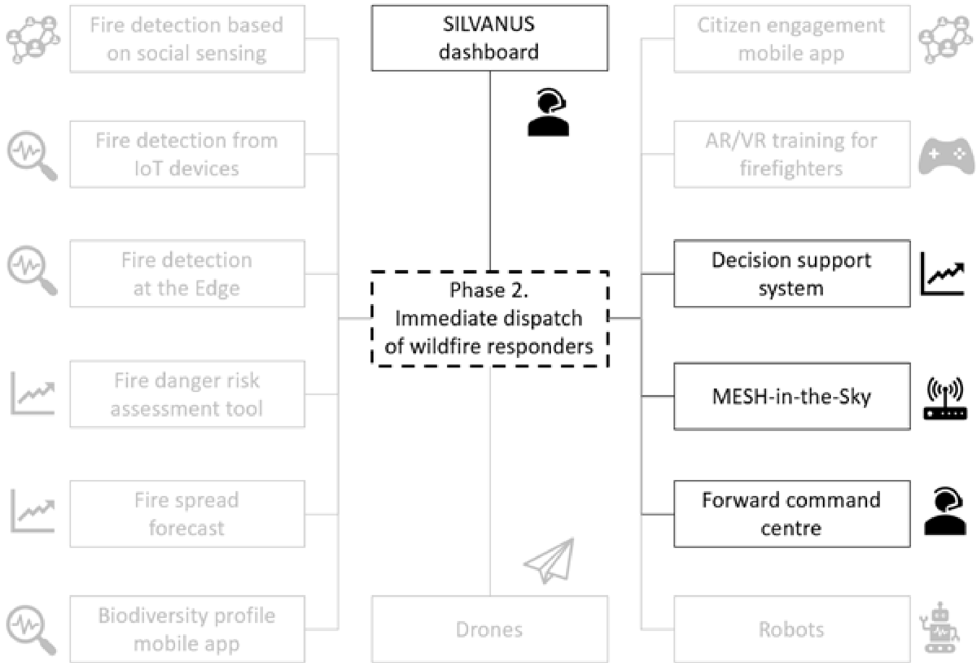


Figure 45. New technologies in protocols of wildfire response training regarding phase 2 – immediate dispatch of wildfire responders

Source: own study

The above-mentioned technologies ensure that the following functionalities to meet operational needs and prepare trainees to complete their tasks effectively:

1) The forward command centre – monitoring of current qualitative and quantitative needs of resources for wildfire response and analysing those needs, direct alerting of wildfire responders and dispatching to action, coordinating the dispatch of the alerted responders,
2) MESH-in-the-Sky – establishing effective communication network to be used for alerting and information exchange.

3) Decision support system – an in-depth analysis to optimise resources to be dispatched given the fire risk and the fire spread forecast.
4) SILVANUS dashboard – visualising the danger zone, location of wildfire responders and optimisation results.

The presented technologies may shape protocols of wildfire response training regarding general functionalities specified below:

1) specification of recourses required for effective response to a wildfire:
   a) decision support system,
   b) citizen engagement mobile app,
   c) SILVANUS dashboard;
2) detection of fire-related threats that may additionally leverage the adjusting of dispatching procedures to the basic situational picture:
   a) forward command centre,
   b) MESH-in-the-Sky,
   c) decision support system,
   d) SILVANUS dashboard;
3) upgrading the situational picture by information about firefighting resources sent to the response:
   a) forward command centre,
   b) MESH-in-the-Sky,
   c) decision support system,
   d) SILVANUS dashboard.

In terms of the potential of particular solutions, training to prepare and pre-plan for wildfire response that focuses on immediate dispatch of wildfire responders may be organised based on the example training protocol presented in Table 34.

Table 34. Illustrative training protocol for immediate dispatch of wildfire responders

No.	Training activity	Supporting technology
1	Specification of recourses required to effectively respond to a wildfire	The SILVANUS dashboard allows verifying entities and resources ready for action (that remain at dispatch)

No.	Training activity	Supporting technology
2	Detection of fire-related threats that may affect the adaptation of dispatching procedures to the basic situational picture	The SILVANUS dashboard operator completes the situational picture with the use of decision support system and information collected in the forward command centre MESH-in-the-Sky ensures communication network to compile the necessary information
3	Adjustment of dispatching procedures to the basic situational picture	The SILVANUS dashboard operator adjusts dispatching procedures to the basic situational picture created with the use of decision support system and information compiled in the forward command centre MESH-in-the-Sky ensures informing of relevant changes

Source: own study

The reference training forms and methods in this case include technology presentation, practical exercises, classical problem method, simulation and case studies. This protocol can be used for the purposes of preliminary training session or a checklist to organise a training session simultaneously with field exercises when a firefighting training is planned.

The immediate dispatch of wildfire responders is not a complex activity in comparison to, for example, comprehensive reconnaissance of a hazard situation or cooperation between firefighting actors. The set of activities to be practiced is specific and relatively intuitive. The deployment of the forward command centre, MESH-in-the-Sky, decision support system and SILVANUS dashboard means a potential of integration with other technologies and connection to other wildfire response phases. From this viewpoint, training related to immediate dispatch of wildfire responders can prove to be a valuable, low-effort complement to other training courses related to wildfire response.

5.3. Effective delivery of resources to the wildfire scene

From the perspective of wildfire response effectiveness, the time between dispatch of the responders to action and the direct application of firefighting jets and other response activities needs to be as short as possible. This requires choosing optimal arrival routes with respect to the location and range of the danger zone, location of wildfire responders, road network, water sources, infrastructure, natural terrain barriers, etc.

Effective delivery of resources to the wildfire scene is related to specific operational needs. The needs are references to objectives and scope of the training. An in-depth analysis of the wildfire phenomenon and wildfire response standards as well as good practices (mentioned in section 3.5.) allows formulating the below specified general needs:

a) to indicate the hazard location (danger zone),
b) to predict scenarios of hazard development that may determine arrival routes,
c) to consider evacuation of people on potential arrival routes,
d) to share information about optimal arrival routes among wildfire responders.

As regards the identified operational needs, information about road neatwork and its limitations, arrival route optimisation, arrival appropriate to wildfire spreading, access to water and infrastructure needed and the evacuation process, should determine the use of relevant technologies to achieve training goals.

Training for wildfire response that regards effective delivery of resources to the wildfire scene relates to a number of technologies, which may significantly facilitate making arrival decisions. The technologies are presented on Figure 46.

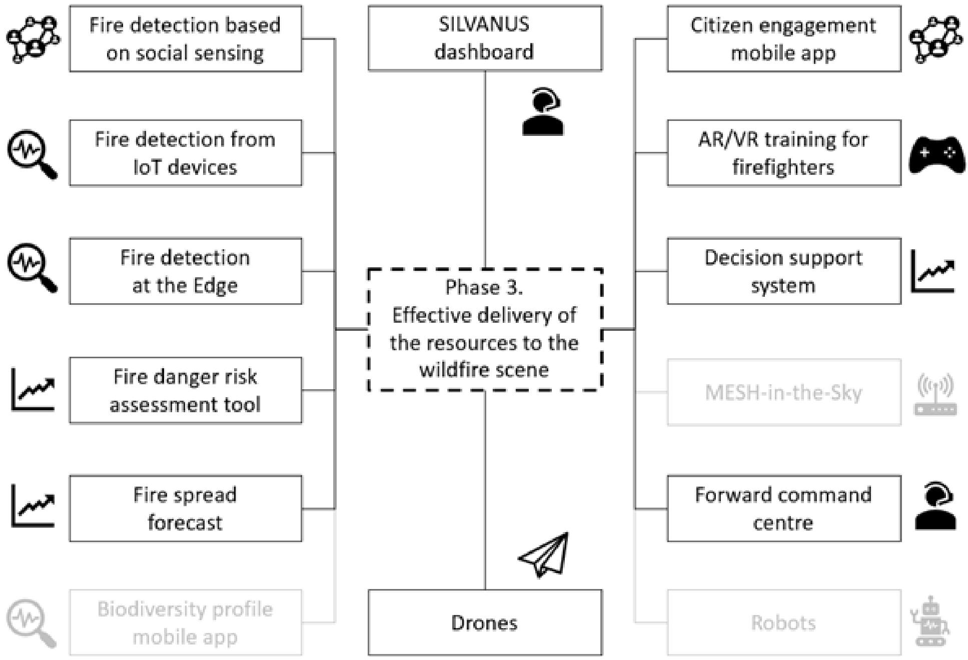


Figure 46. New technologies in protocols of wildfire response training regarding phase 3 – effective delivery of resources to the wildfire scene

Source: own study

The above-mentioned technologies ensure that the following functionalities meet operational needs and prepare the trainees to complete effectively their tasks:

1) Fire detection based on social sensing – defining the location and range of wildfire manifestations, and safe arrival routes to cross-check with other detection solutions.
2) Fire detection from IoT devices – defining the location and range of wildfire manifestations, and safe arrival routes to cross-check with other detection solutions.
3) Fire detection at the Edge – defining the location and range of wildfire manifestations, and safe arrival routes to cross-check manner with other detection solutions.
4) Fire danger risk assessment tool – defining the arrival zones characterised by the highest fire risk in the given conditions to determine other arrival routes.
5) Fire spread forecast – simulating the fire development to exclude arrival routes when simulation scenario premises materialise.
6) Drones – setting up a platform for cameras and sensors to check safe arrival routes.

7) Forward command centre – optimising arrival routes on the basis of gathered information and the situational forecast.
8) Decision support system – defining high risk areas in the woods and evacuation routes, analysing conditions for the effective and safe arrival to a wildfire scene.
9) AR/VR training for firefighters – simulating conditions of arrival to the wildfire scene in various terrain conditions, and different scenarios of fire development and evacuation.
10) Citizen engagement mobile app – communicating information about the necessity of ensuring passable roads (especially when the roads serve simultaneously for evacuation purposes).
11) SILVANUS dashboard – visualising the road network and results or arrival optimisation, cross-checking detection results of wildfire manifestations, and defining the danger to adjust arrival routes.

The presented technologies may shape protocols of wildfire response training regarding the general below specified functionalities:

1) identifying and warning about fire-related threats:
   a) fire detection based on social sensing,
   b) fire detection from IoT devices,
   c) fire detection at the Edge,
   d) fire danger risk assessment tool,
   e) fire spread forecast,
   f) drones,
   g) forward command centre,
   h) decision support system,
   i) AR/VR training for firefighters,
   j) citizen engagement mobile app,
   k) SILVANUS dashboard;
2) in-depth analyses and adjusting arrival routes to the situational picture:
   a) fire detection based on social sensing,
   b) fire detection from IoT devices,
   c) fire detection at the Edge,
   d) fire danger risk assessment tool,
   e) fire spread forecast,
   f) drones,
   g) forward command centre,
   h) decision support system,

   i) citizen engagement mobile app,
   j) SILVANUS dashboard;
3) in-depth analyses from multiple perspectives:
   a) fire detection based on social sensing,
   b) fire detection from IoT devices,
   c) fire detection at the Edge,
   d) fire danger risk assessment tool,
   e) fire spread forecast,
   f) drones,
   g) decision support system,
   h) citizen engagement mobile app,
   i) SILVANUS dashboard;
4) visualising the situational picture:
   e) forward command centre,
   f) decision support system,
   g) AR/VR training for firefighters,
   h) citizen engagement mobile app,
   i) SILVANUS dashboard.

As regards the potential of particular solutions, training that focuses on effective delivery of resources to the wildfire scene may be organised using the example training protocol presented in Table 35.

Table 35. Example training protocol for effective delivery of resources to the wildfire scene

No.	Training activity	Supporting technology
1	Marking preliminary arrival routes and the concentration point of firefighting resources	Fire danger risk assessment, fire spread forecast and IoT devices are used to indicate areas where arrival routes may be affected by a fire with high probability
2	Adjustment of arrival routes to current situational picture	The SILVANUS dashboard operator uses social sensing solutions to identify secondary threats that leverage arrival routes and routes are adjusted to current situational picture Firefighter uses a drone to check and mark arrival route in the woods due to fire-related threats and terrain conditions

No.	Training activity	Supporting technology
3	Evaluation of situational picture and arrival routes	The SILVANUS dashboard operator compiles and updates information related to fire danger risk assessment, fire spread forecast, social sensing, IoT devices, the use of drones and citizen engagement app and also shares it among wildfire responders to make common situational picture
4	Leveraging traffic conditions to make delivery of firefighting resources to the wildfire scene more effective and unhindered	The citizen engagement app is used to inform citizens about the necessity of evacuation and/or adjusting traffic conditions to the need of assuring effective arrival of firefighters to the response scene

Source: own study

The reference training forms and methods in this case comprise technology presentation, practical exercises, classical problem method, simulation and case study. Table top exercises are also valuable. This protocol can be used for the purposes of secondary training session for a training focused on immediate dispatch of wildfire responders or a checklist for organising a training session simultaneously with field exercises when the training organiser plans firefighting activities in the training curriculum.

Specifics of terrain conditions in the woods and the dynamism of wildfire phenomenon may significantly impede effective delivery of resources to the wildfire scene. Thus, in-depth and multi-directional analyses of hazard situation should be implemented in preparation and pre-planning activities. As the forward command centre, the decision support system and the SILVANUS dashboard are taken into consideration, training on delivery of resources can become a part of wider educational perspective (for example by connection to training related to other phases of wildfire response).

5.4. Comprehensive identification of hazard situation

Effective response to a wildfire is depends on the correctness of tactical decisions to be made by emergency managers, disaster managers, crisis managers and commanders on the scene. The more accurate information gathered, the higher chance to get an operational picture that allows making adequate decisions. As wildfire is a complex phenomenon determined by multiple factors, wildfire responders have limited influence on these factors, and specific response needs to be implemented in cooperation, recognition of hazard situation should be comprehensive. Training plays a significant role in the optimisation, exercising and enhancing of recognition abilities. It is very important to obtain a situational picture that reflects real circumstances and conditions of wildfire response.

The comprehensive recognition of the hazard situation is related to specific operational needs of wildfire responders. These needs should be identified as references to training objectives and scope. An in-depth analysis of the wildfire phenomenon and wildfire response standards and good practices (mentioned in section 3.5.) allow formulating the general needs that are enumerated below:

a) to integrate reconnaissance efforts,
b) to cooperate reconnaissance efforts,
c) to confirm the situational picture shaped preliminarily during previous wildfire response phases,
d) to monitor a wildfire,
e) to monitor secondary and co-existing hazards to a wildfire,
f) to inform stakeholders about changes in situational picture.

Many technologies can support training dedicated to comprehensive reconnaissance of the hazard situation. From the practical point of view, they need to consider multiple reconnaissance tools and procedures, getting information from different sources, verifying the correctness of information, effective communication with the commander and other stakeholders (for example the police, forest service, armed forces), and alternative reconnaissance ways.

In the context under consideration, all SILVANUS-related technologies may be useful for comprehensive reconnaissance of the hazard situation. The essential issue is to use them in the proper way. Figure 47 demonstrates their general catalogue.

The specified technologies ensure the following functionalities necessary to meet operational needs and prepare trainees to complete their tasks effectively:

1) Fire detection based on social sensing – confirming the fire outbreak in social media with supporting information (text, photos, movies, geolocation,

etc.) on the hazard location to cross-check with other detection solutions, and identifying secondary and co-existing hazards.

2) Fire detection from IoT devices – confirming the occurrence of fire manifestations (flames, smoke, thermal radiation) in the effective detection range of IoT devices with supporting information (geolocation of a sensor, detection direction) to cross-check with other detection solutions, and identifying secondary and co-existing hazards.

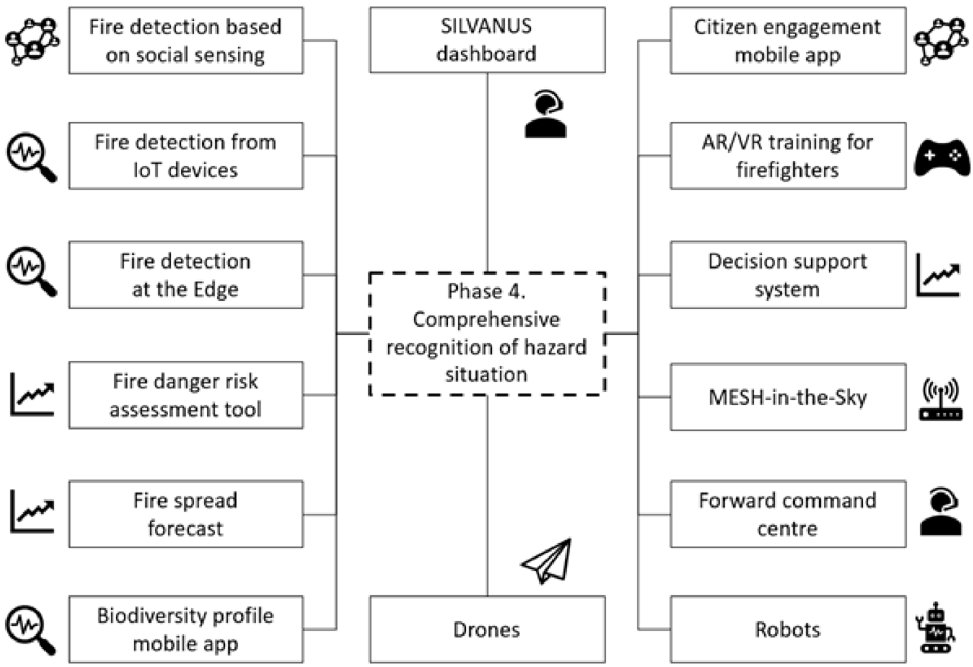


Figure 47. New technologies in protocols of wildfire response training for phase 4 – comprehensive reconnaissance of the hazard situation

Source: own study

3) Fire detection at the Edge – confirming the occurrence of fire manifestations (flames, smoke) with the direct location of a hazard in the woods as a cross-check manner to other detection solutions, and identifying secondary and co-existing hazards.

4) Fire danger risk assessment tool – secondary appointment of hazard zones characterised by the highest fire risk in the given conditions to focus detection and reconnaissance activities on these areas along the line of cascading effect of hazard development.

5) Fire spread forecast – simulating fire development to appoint the most vulnerable areas in the woods to focus detection and reconnaissance activities on these areas along the line of cascading effect of hazard development.
6) Biodiversity profile mobile app – analysis of fire load and fire vulnerability on areas surrounding the danger zone to feed risk assessment and fire spread forecast algorithms.
7) Drones – providing a platform for multiple sensors and other devices to proceed with reconnaissance activities from the air perspective.
8) Robots – providing a platform for multiple sensors and other devices to proceed with reconnaissance activities from the ground perspective.
9) Forward command centre – monitoring of social media, supervising detection and reconnaissance equipment, collecting detection and reconnaissance information, confirming the occurrence of a hazard and its development, and communicating relevant information to stakeholders.
10) MESH-in-the-Sky – establishing effective communication network for detection, reconnaissance and communication processes.
11) Decision support system – in-depth analyses of wildfire conditions on the basis of information compiled during a reconnaissance.
12) AR/VR training for firefighters – using the virtual world to conduct particular reconnaissance activities.
13) Citizen engagement mobile app – communicating information about a hazard and its development to social media, moderating proper behavioural patterns among citizens to safely and effectively face a danger situation.
14) SILVANUS dashboard – visualising reconnaissance results, cross-checking detection results, and evaluating the situational picture on a map.

The presented technologies may shape protocols of wildfire response training regarding the below specified general functionalities:

1) profiling the wildfire risk in the given area:
   a) fire detection based on social sensing,
   b) fire detection from IoT devices,
   c) fire detection at the Edge,
   d) fire danger risk assessment tool,
   e) fire spread forecast,
   f) biodiversity profile mobile app,
   g) decision support system,

   h) citizen engagement mobile app,
   i) SILVANUS dashboard;
2) collecting information about the current location of wildfire manifestations and derivative threats:
   a) fire detection based on social sensing,
   b) fire detection from IoT devices,
   c) fire detection at the Edge,
   d) fire danger risk assessment tool,
   e) fire spread forecast,
   f) drones,
   g) robots,
   h) forward command centre,
   i) MESH-in-the-Sky,
   j) decision support system,
   k) citizen engagement mobile app,
   l) SILVANUS dashboard;
3) integrating and visualising a common situational picture:
   a) forward command centre,
   b) MESH-in-the-Sky,
   c) decision support system,
   d) citizen engagement mobile app,
   e) SILVANUS dashboard;
4) simulating reconnaissance activities:
   a) decision support system,
   b) AR/VR training for firefighters,
   c) SILVANUS dashboard.

As regards the potential of particular solutions, training focused on comprehensive identification of the hazard situation may be organised according to the exemplary training protocol presented in Table 36.

Table 36. Exemplary training protocol for comprehensive recognition of hazard situation

No.	Training activity	Supporting technology
1	Compiling information to determine the wildfire risk in the given area	Fire danger risk assessment, biodiversity profile mobile app, fire spread forecast and social sensing solutions are used to collect basic information necessary to indicate places where the fire risk is the most severe
2	Profiling the wildfire risk in the given area	The SILVANUS dashboard operator marks places where the fire risk is the most severe
3	Compiling information directly from the action scene	The trainees use AR/VR tools to survey the wildfire scene and compile all information that determines firefighting tactics and cooperation with other entities responding to a fire
4	Making simulations on wildfire development based on the risk assessment results and information compiled	The SILVANUS dashboard operator or an analyst carried out simulations of the hazard development with the use of fire danger risk assessment and fire spread forecast
5	Marking arrival routes, evacuation routes and points of concentration of firefighting resources	The drone operator checks arrival routes, evacuation routes and points of concentration of firefighting resources from the air The robot operator controls arrival routes, evacuation routes and points of concentration of firefighting resources from the ground (where a drone was not able to get sufficient information) The SILVANUS dashboard operator marks arrival routes, evacuation routes and points of concentration of firefighting resources in the system and shares the common situational picture MESH-in-the-Sky ensures communication abilities

6	Visualising a common situational picture	The SILVANUS dashboard operator shares the common situational picture among wildfire responders MESH-in-the-Sky ensures communication abilities

Source: own study

The reference training forms and methods comprise talks, lectures, discussions and technology presentations. As comprehensive identification of hazard situation is relatively complex, table top exercises are worth of organising. Moreover, the recognition training can be organised with the practical use of end-technology devices. It is a good practice to organise it in the woods to confront trainees with challenging terrain conditions. However, field exercises require paying special attention on safety issues and access to technical support staff. The training organiser is obligated to consider those aspects.

When considering the involvement of attendees from several safety and security entities, it is necessary to assure them access to the common information space. The forward command centre, decision support system, MESH-in-the-Sky and SILVANUS dashboard are able to handle this need and prepare different responders to execute common recognition efforts during the same training session. To maximise the educational effect, training dedicated to comprehensive recognition of hazard situation can be associated with training courses that regard other wildfire response phases, in particular early detection of a hazard, firefighting tactics, and cooperation between firefighting actors.

5.5. Firefighting tactics

Firefighting tactics means decisions concerning the optimal use of resources necessary to put out a fire. It is gaining importance especially in the woods, where inappropriate decisions may affect the hazard development and cause additional damage and losses to humans, animals, natural environment and property. An uncontrolled fire may pose danger to national security if critical infrastructure is localised in the danger zone. This justifies the necessity of using wildfire responders according to fire risk, terrain conditions, weather conditions, available resources and the hazards that accompany a fire.

Firefighting tactics are linked to specific operational needs expressed by wildfire responders. These needs should be identified as references for the training objectives and scope. An in-depth analysis of the wildfire phenomenon and wildfire response standards and good practices (mentioned in section 3.5.) allows formulating the below specified general needs:

a) to integrate the situational picture,
b) to monitor changes in conditions of a wildfire and firefighting operation, and evaluate the situational picture,
c) to indicate tactical needs (what should be precisely done to protect people, the natural environment and property against to a fire and its consequences),
d) to analyse accessible resources,
e) to verify quantitative and qualitative accurateness of available resources,
f) to formulate a tactical intent,
g) to inform responders of tactical intent,
h) to monitor the implementation of tactical intent.

As regards the identified operational needs, first stage tactics formulation, division of hazard scene into operational areas, the optimal use of resources, reflecting forest environment (opportunities and threats), the implementation of best operational practices should determine the use of relevant technologies to achieve training goals.

Training that regards firefighting tactics may draw on nearly all functionalities described as the reference ones in the context of preparation and pre-planning activities for wildfire response. They are synthetically presented on Figure 48.

The specified technologies ensure the following functionalities to meet operational needs and prepare trainees to complete effectively their tasks:

1) Fire detection based on social sensing – referring tactical intent to location of a fire, additional hazards and societal needs on the basis of social sensing results, and updating the situational picture.
2) Fire detection from IoT devices – referring tactical intent to the location of a fire on the basis of social sensing results, and updating the situational picture.
3) Fire detection at the Edge – referring tactical intent to the location of a fire and additional hazards on the basis of social sensing results, and updating the situational picture.

4) Fire danger risk assessment tool – updating information on hazard zones characterised by the highest fire risk in the given conditions to focus firefighting activities on these areas along the line of the cascading effect of hazard development.
5) Fire spread forecast – simulating fire development to adjust tactical assumptions and intent.

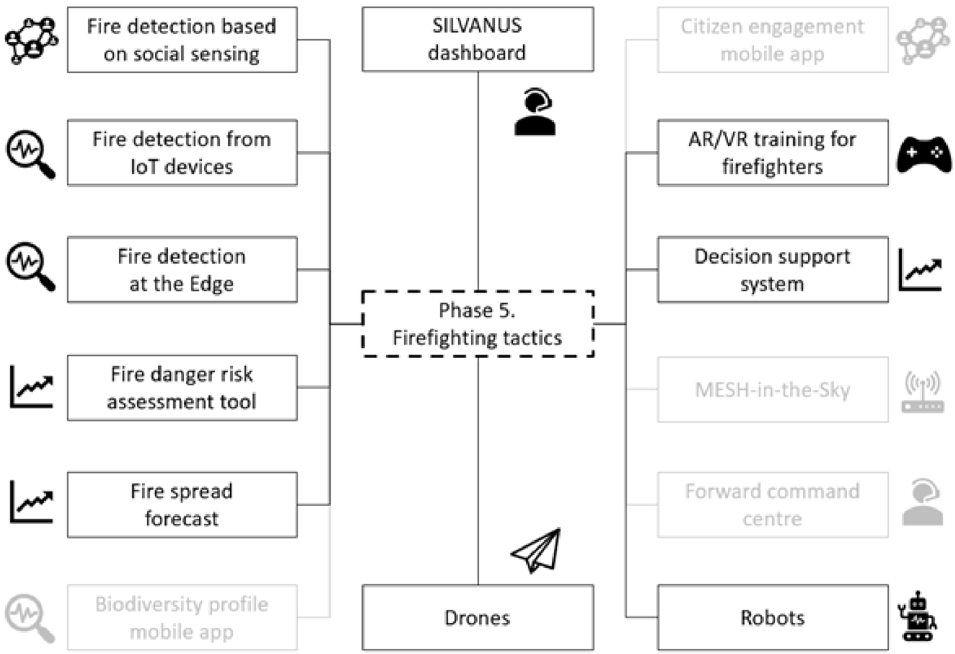


Figure 48. New technologies in protocols of wildfire response training regarding phase 5 – firefighting tactics

Source: own study

6) Drones – providing a platform for multiple sensors and other devices to proceed with reconnaissance activities from the air perspective, executing extinguishing activities, and monitoring firefighting effectiveness.
7) Robots – providing a platform for multiple sensors and other devices to proceed with reconnaissance activities from the ground perspective, and conducting extinguishing activities.
8) Decision support system – optimising tactical decisions and suggesting tactical intent.

9) AR/VR training for firefighters – training firefighting activities and making command decisions on the basis of current situational picture.
10) SILVANUS dashboard – compiling information to shape situational awareness (appropriately to wildfire conditions, resources, and firefighting progress), and making tactical intent, sharing tactical information among users.

The presented technologies may shape protocols of wildfire response training regarding the below specified general functionalities:

1) ad-hoc profiling of the wildfire risk in a given area:
   a) fire detection based on social sensing,
   b) fire detection from IoT devices,
   c) fire detection at the Edge,
   d) fire danger risk assessment tool,
   e) fire spread forecast,
   f) drones,
   g) robots,
   h) decision support system,
   i) SILVANUS dashboard;
2) compiling information about the current location of wildfire manifestations and derivative threats:
   a) fire detection based on social sensing,
   b) fire detection from IoT devices,
   c) fire detection at the Edge,
   d) fire danger risk assessment tool,
   e) fire spread forecast,
   f) drones,
   g) robots,
   h) decision support system,
   i) SILVANUS dashboard;
3) integrating and visualising a common situational picture:
   a) fire detection based on social sensing,
   b) fire detection from IoT devices,
   c) fire detection at the Edge,
   d) fire danger risk assessment tool,
   e) fire spread forecast,
   f) drones,
   g) robots,

    h) decision support system,
    i) AR/VR training for firefighters,
    j) SILVANUS dashboard;
4) simulating firefighting activities:
    a) decision support system,
    b) AR/VR training for firefighters,
    c) SILVANUS dashboard.

As regards the potential of particular solutions, training that focuses on firefighting tactics may be organised for the exemplary training protocol presented in Table 37.

Table 37. Exemplary training protocol for firefighting tactics

No.	Training activity	Supporting technology
1	Compiling information to divide the wildfire response theatre into several firefighting sections with relevant sub-commanders (each sub-commander responsible for one section and subordinated to the primary commander)	IoT devices, fire danger risk assessment and fire spread forecast and the SILVANUS dashboard provide information input to facilitate the division of wildfire response theatre into several firefighting sections
2	Marking defence lines	Access to the SILVANUS dashboard allows analysing a forest map to find out places and objects useful to elaborate defence lines (for example roads, rivers, boundaries of forest divisions, etc.)
3	Planning the allocation of firefighting resources (engines, pumps, water containers, drone/robot operators, ground teams, etc.)	Maps and information collected by drone/robot operator allows to plan location of firefighting resources

No.	Training activity	Supporting technology
4	Planning the back-burning area	Fire danger risk assessment and fire spread forecast are used by the SILVANUS dashboard operator to indicate places for back-burning Field firefighter uses biodiversity mobile app to feed the fire danger risk assessment and the fire spread forecast tools directly from the field
5	Indicating places to make firefighting drops from a helicopter and/or a plane	Analysts carry out danger development simulations to preliminarily indicate places to make firefighting drops from a helicopter and/or a plane A UAV operator verifies the places and evaluate its activities (to not pose danger to a plane or a helicopter)
6	Analysing water supply sources and marking the location of water supply lines	The SILVANUS dashboard operator carries out a geo-spatial analysis to mark location of water supply sources and water supply lines The robot operator conducts additional reconnaissance to verify the location of water supply lines Drone operator monitor water supply lines
7	Analysing the necessity and conducting the evacuation of people from the danger zone	The SILVANUS dashboard operator monitors social media to identify the necessity of evacuating people from the danger zone The SILVANUS dashboard operator sends guidelines concerning evacuation necessity, evacuation directions, evacuation roads and proper behavioural patterns to social media users The drone operator uses UAVs to show people in the danger zone an evacuation route

No.	Training activity	Supporting technology
8	Conducting firefighting activities	Firefighters use AR/VR solutions to practice such firefighting activities as moving vehicles in danger zone, extinguishing a fire, making back-burning, ground navigating to a helicopter Firefighters set up a firefighting post on the basis of a robot Firefighters navigate a drone to analyse firefighting tactics from the air The UAV delivers first aid kit to field firefighters The UGV evacuates injured firefighters from the danger zone

Source: own study

Training forms and methods ensuring effective facing of training goals could comprise practical exercises and field exercises. Talks and discussions may be used to preliminarily prepare attendees to the essential part of a training course. Also needed is a presentation of technology. It gains in importance when end-technology tools (drones, robots, etc.) are expected. In such circumstances, direct access to relevant technology providers may be necessary. It is worth highlighting that the presented training protocol is an example of technology connection aimed at organising training for wildfire response. Complex catalogues of solutions associated to general functionalities shaping the training protocol highlight many other possibilities of connecting technologies to achieve training objectives.

Training in firefighting tactics may be organised on the basis of a number of scenarios. It is hard to imagine that a single training session is able to cover all tactical intents and firefighting activities. It is a good practice to map tactical scenarios and organise a set of training sessions to allow their implementation. In addition, the recommended technologies prove that training in firefighting tactics is quite closely related to training in comprehensive recognition of hazard situations. Combination of these two wildfire response phases into a single training session may provide a synergy effect and make educational processes more efficient.

5.6. Cooperation between firefighting entities

The fire service is the primary wildfire responder for direct firefighting in the woods. Particular countries have at their disposal own resources to face a wildfire and eliminate relevant hazards. However, when a wildfire is a disaster trigger, external support is required. This applies both to involving the fire service from other countries (for example by launching the Union Civil Protection Mechanism) and obtaining support from other kinds of entities (the police, the armed forces, public administration etc.). Consequently, wildfire responders need to be well-prepared for cooperation between firefighting actors to generate synergy effect and maximise their common efforts.

Cooperation between firefighting actors addresses specific operational needs expressed by wildfire responders. These needs should be identified as references for training objectives and scope. An in-depth analysis of the wildfire phenomenon and of wildfire response standards and good practices (mentioned in section 3.5.) allows formulating the below specified general needs:

a) integrating the situational picture,
b) identification of operational needs to be met by particular firefighting actors,
c) analysing accessible resources,
d) verification of quantitative and qualitative accurateness of available resources,
e) assessment of a tactical intent (if necessary),
f) informing responders of new tactical intent,
g) monitoring the implementation of new tactical intent.

Because the cooperation between firefighting actors is a complex undertaking, technological support is required. This also applies to educational processes intended to prepare and pre-plan the cooperation for wildfire response. Effective risk and crisis communication, optimisation of the use of resources, hazard monitoring issues, alternativeness of entities, and mutual-securing of entities should be taken into account.

Even if a wildfire is determined by mechanisms caused by nature (including weather conditions, terrain conditions, etc.), it may develop in multiple ways. It is a dynamic phenomenon and the responders need to be prepared for a number of operational scenarios. The response may require strong cooperation between firefighters and other entities (for example forest service, armed forces, police troops, critical infrastructure operations, volunteers, etc.). This is why new technologies should be deployed when about it comes to cooperation between firefighting actors. The relationships between the technologies and the Phase 6 are presented on Figure 49.

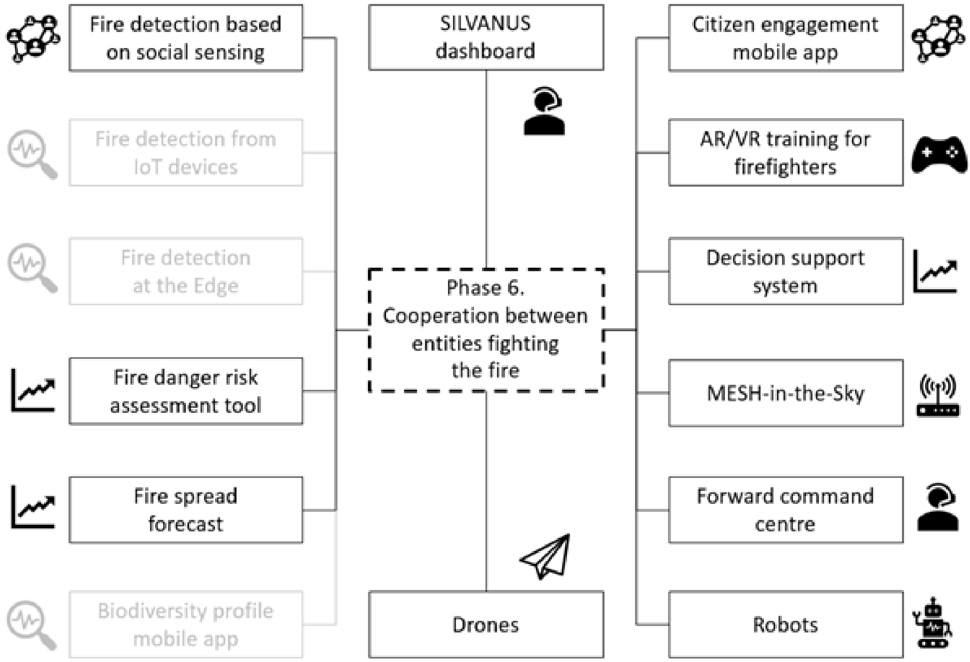


Figure 49. New technologies in protocols of wildfire response training regarding to phase 6 – cooperation between firefighting entities

Source: own study

The presented technologies may shape protocols of wildfire response training with respect to the below specified general functionalities:

1) ad-hoc profiling of the wildfire risk in the given area:
   a) fire detection based on social sensing,
   b) fire danger risk assessment tool,
   c) fire spread forecast,
   d) drones,
   e) robots,
   f) decision support system,
   g) SILVANUS dashboard;

2) compiling information about the current location of wildfire manifestations and derivative threats:
   a) fire detection based on social sensing,
   b) fire danger risk assessment tool,
   c) fire spread forecast,
   d) drones,
   e) robots,
   f) decision support system,
   g) SILVANUS dashboard;
3) integrating and visualising a common situational picture:
   a) fire detection based on social sensing,
   b) fire danger risk assessment tool,
   c) fire spread forecast,
   d) drones,
   e) robots,
   f) forward command centre,
   g) MESH-in-the-Sky,
   h) decision support system,
   i) citizen engagement mobile app,
   j) SILVANUS dashboard;
4) simulating response activities:
   a) fire danger risk assessment tool,
   b) fire spread forecast,
   c) forward command centre,
   d) MESH-in-the-Sky,
   e) decision support system,
   f) AR/VR training for firefighters,
   g) citizen engagement mobile app,
   h) SILVANUS dashboard.

As regards the potential of particular solutions, training that focuses on cooperation between firefighting actors may be organised regarding the exemplary training protocol presented in Table 38.

Table 38. Exemplary training protocol for cooperation between firefighting actors

No.	Training activity	Supporting technology
1	Compiling information to divide wildfire response theatre for firefighters and other response entities	IoT devices, fire danger risk assessment, fire spread forecast and the SILVANUS dashboard provide information input allow facilitating the division of wildfire response theatre into several entities
2	Setting out safety zones	Fire danger risk assessment, fire spread forecast and the SILVANUS dashboard provide information input allow differentiating the response scene on the basis of multiple safety levels – as a rule only firefighters should have access to the zone characterised by the highest risk
3	Air monitoring of common wildfire response efforts	The UAV operator monitors common wildfire response efforts from the air and reports any operational needs
4	Ground monitoring of common wildfire response efforts	The UGV operator monitors common wildfire response efforts from the ground and reports any operational needs
5	Sharing common operational picture	The SILVANUS dashboard operator shares operational picture among all entities involved in the wildfire response
6	Adjusting societal behaviour	The primary commander uses social media to analyse societal behaviour related to wildfire and wildfire response, and obtain support from other entities (for example from police troops to ensure public safety and manage mass evacuation from danger zone)
7	Simulating response activities	Firefighters use AR/VR tools to simulate cooperation between other wildfire responders (for example regarding medical rescue, evacuation of people, navigating planes and helicopters)

Source: own study

The reference training forms and methods comprise table top exercises, didactic games and field exercises. Technology presentations may facilitate familiarisation with particular technological tools but it should not be the essential part of a training course. The most important issue is to assure conditions and abilities to generate a synergy effect that stems from cooperation. Consequently, attendees should have access to training materials with information about operational needs of particular co-operators and cooperation standards. They need to know what, who, when, how and in what way should be done when responding to a wildfire. This knowledge needs to be gained before the training part organised in field conditions (in the woods). It is crucial to maximise the educational effect as well as to create space to focus primarily on cooperation aspects.

The need for access to the common information space must be emphasized when considering the involvement of attendees from multiple safety and security entities for collaborative training in the forest. The forward command centre, decision support system, MESH-in-the-Sky and the SILVANUS dashboard make possible ensuring this space but come with organisational challenges to familiarise many trainees with many technological solutions. As far as practical issues are concerned, cooperation between firefighting actors can be dealt with only in the phase of wildfire response. It may also cross-cut all response phases and refer to early detection and communication of a hazard (when different entities are involved to detection process), immediate dispatch of wildfire responders (if the dispatch can be executed by different centres and dispatching points), effective delivery to a wildfire scene (for example with police in support on arrival roads), comprehensive recognition of the hazard situation (by involving non-public device operators and volunteers), and firefighting action (after launching of the Union Civil Protection Mechanism, etc.). This sheds light on a multitude of training possibilities and significant potential of new technologies in support of wildfire response.

Conclusion

The monograph entitled *The SILVANUS Handbook on Systematic Methodology for the Preparation and Pre-planning Activities for Wildfire Response* focuses on developing a systematic approach to train and prepare for wildfire response. The objective of the research, reflected in the five chapters of the book, was to establish a framework that integrates modern technologies and strategic protocols to enhance the effectiveness of wildfire response training.

The central research problem was to identify a systematic methodology for preparing and pre-planning activities for wildfire response. Specifically, the authors aimed to answer the question: *What systematic methodology allows the effective preparation and pre-planning of activities for wildfire response?* The hypothesis posited that a well-structured methodology incorporating wildfire-specific conditions, modern technologies and a training framework would significantly improve wildfire preparation through training. As this monograph demonstrates, the hypothesis was positively evaluated and confirmed. A comprehensive methodology, as proposed, not only integrates modern technological tools but also considers wildfire-specific factors, allowing the formulation of effective training protocols.

Chapter 1 provides fundamental understanding of wildfires by examining the causes, types, and environmental conditions that facilitate their spread. This chapter outlines the need for specific approaches to managing different types of wildfires. Key points covered comprise the definition of wildfires, conditions leading to their outbreak, and the classification of wildfires based on their behaviour and location. Furthermore, the chapter also elaborates on the process of wildfire response, highlighting the need for a thorough understanding of hazard conditions to plan appropriate response strategies. By understanding these dynamics, training programmes can be better tailored to address the unique challenges posed by wildfires.

Chapter 2 focuses on the role of training in preparing responders for wildfire scenarios. This chapter emphasizes that training is not only a way of transferring knowledge about wildfire behaviour and firefighting tactics but also a flexible method to introduce modern technologies to responders. The chapter details the training needs stemming from the specifics of wildfire response, including the necessary participants and equipment. The universality of the training, combined with the flexibility of incorporating modern technology like drones and communication systems, is central to improving preparedness.

Chapter 3 elaborates on the core methodology that drives the preparation and pre-planning of wildfire responses. The SILVANUS approach is defined through a "step-by-step" formula, which structures training around compiling essential information for developing curricula in a replicable and rational manner. This methodology focuses on key elements such as training objectives, forms, methods, and materials. Emphasis is placed on the integration of technology into the training processes, making modern solutions like UAVs, decision support systems, and communication platforms part of the core training curricula. This chapter also presents training guidelines that are designed to be operational and adaptable, ensuring that they can be applied to multiple contexts.

In the chapter *The Role of Technology in Training for Wildfire Response* the focus shifts to technological tools that can support wildfire response training. The analysis here involves a deep dive into how modern technologies such as detection systems, computational tools, and societal involvement solutions can be employed in wildfire management. Each technological solution is examined for its relevance in different phases of wildfire response – such as early detection, resource mobilization, hazard assessment, and tactical firefighting cooperation. The chapter highlights how these technologies can be seamlessly integrated into training protocols to enhance educational outcomes, improve preparedness, and optimize resource utilization.

The final chapter focuses on the practical application of the methodology and technologies discussed in earlier chapters. This section emphasizes the "step-by-step" methodology in developing training protocols. It breaks down wildfire response into various stages: early detection, immediate response deployment, resource allocation, hazard recognition and tactical cooperation. For each phase, training recommendations are provided along with guidance on using specific technologies. The chapter effectively translates theoretical and technological insights into actionable training plans that responders can use to manage wildfires more effectively.

The research outlined in this monograph confirms the hypothesis that a systematic approach to wildfire response training can significantly enhance preparation and preparedness for wildfire response. By integrating modern technologies and developing clear, structured protocols, the proposed methodology ensures that wildfire responders are well-equipped to manage emergencies efficiently.

However, as with any research, there is always room for further investigation. Future research could explore the following areas:

1. Customization of Training Protocols for Different Regions: Given the diverse environmental conditions that influence wildfire behaviour globally, future research could focus on tailoring training protocols to regional and local needs.
2. Advanced Technological Integration: While this research focused heavily on the use of UAVs, detectors, decision support systems, analytical solutions and communication tools, the integration of AI and machine learning to predict wildfire patterns and automate some of the response processes could be an area for further development.
3. Evaluation of Long-Term Impact: Future research should examine the long-term impact of these training protocols, measuring their effectiveness over extended periods and across multiple wildfire incidents.

Collaboration Between Nations: Given the cross-border nature of wildfires, especially in regions like Europe, further research should investigate how this methodology can be adapted for international cooperation.

In the conclusion, the systematic methodology presented in this monograph provides a robust framework for preparing wildfire responders. With its strong emphasis on integrating cutting-edge technology and structured training, it sets a clear path for enhancing wildfire management. Yet, continuous innovation and region-specific customization remain crucial for future advancements in this field.

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