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# Primena dronova u zaštiti od šumskih požara – bazične strategije za Republiku Srbiju

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**Apstrakt:** U poslednje dve decenije, sve je više šumskih požara usled klimatskih promena. Ovi požari utiču na različite kontinente i države širom sveta pa i na Republiku Srbiju. Kako šumski požari imaju izuzetno negativan uticaj i na ljude, i na sav živi svet u okruženju, razvijaju se različite strategije za borbu protiv šumksih požara koje uključuju upotrebu savremenih tehnologija, baziranih na informacionim tehnologijama i veštačkoj inteligenciji. Jedna od savremenih tehnologija koja se izdvaja kao važan alat za borbu protiv šumskih požara jesu bespilotne letelice, koje se u široj javnosit najčešće nazivaju dornovi. Njihova upotreba je raznovrsna i mnogi načini korišćenja se mogu primeniti i u Republici Srbiji.

Primenom SWOT i TOWS matrice, mogu se definisati četiri ključne strategijie koje podrazumevaju, proizvodnju dronova, poboljšanje tehnoloških sposobnosti postojećih jedinica i dobar uvid u situaciju na terenu, kao i podizanja svesti javnosti o opasnosti od šumskih požara. Takođe se mogu definisati ključni elementi u daljem razvoju strategija: prevencija i monitoring požara, izgradnja svesti kod građana o opasnostima od šumskih požara i koristima od upotrebe dronova, kao i prepoznavanje tehnoloških i ljudskih kapaciteta za razvoj dronova za gašenje požara.

**Ključne reči:** Šumski požari, UAS (dronovi), strategije, Republika Srbija

# Application of drones in forest fire protection - basic strategies for the Republic of Serbia

**Abstract:** In the last two decades, there have been more forest fires than ever due to climate change. These fires affect different continents and countries around the world, including the Republic of Serbia. As forest fires have an extremely negative impact on people and the environment, different strategies are being developed to fight forest fires that include the use of modern technologies, based on information technology and artificial intelligence. One of the contemporary technologies that stand out as an important tool for fighting forest fires are unmanned aerial vehicles, which are commonly called drones. Their use is diverse and many ways of implementation can be applied in the Republic of Serbia.

By applying the SWOT and TOWS matrix, four key strategies are defined, which include the production of drones, improving the technological capabilities of existing units and the situational awareness system, as well as raising public awareness of the danger of forest fires. Key elements in the further development of strategies can also be defined: prevention and monitoring of fires, building awareness among citizens about the dangers of forest fires and the benefits of using drones, as well as recognizing the technological and human capacities for the development of drones for actual firefighting.

**Keywords:** Forest fires, UAS (drones), strategies, Republic of Serbia

# 1. Introduction

In the first decades of the 21st century, due to climatic changes, forest fires are increasingly becoming a global danger that threatens people, but also plant and animal life and leads to new negative impacts on the climate. Numerous fires in the USA (especially in California), Australia, a number of European countries (Spain, France, Greece) (Hristov, Raychev, Kinaneva, & Zahariev, 2018; Kinaneva, Hristov, Raychev, & Zahariev, 2019; Roldán-Gómez, González-Gironda, & Barrientos, 2021; Akhloufi, Couturier, & Castro, 2021; Saffre, Hildmann, Karvonen, & Lind, 2022; Namburu, Selvaraj, Mohan, Ragavanantham, & Eldin, 2023), and an increasing number of forest fires in the Republic of Serbia, indicate the need to create modern fire prevention and defense strategies. New strategies imply the use of new technologies based on artificial intelligence and information technology, but should also take into the account the competencies of people who develop and apply these strategies.

Numerous academic and professional research points to new technologies that can be used in prevention, control, firefighting, and UAS (Unmanned Aircraft Systems), i.e. drones, as they will be called in the following text, stand out as one of the most important tools (Ilić, Milošević, & Ilić-Kosanović, 2022; Zhang, Srivastava, & Eachempati, 2023). In this paper, an analysis of the literature on the use of drones in fire protection will be carried out, and then, based on the results of the literature review, an assessment of potential strategies for the use of drones to fight forest fires in the Republic of Serbia was carried out. In the research, the aspects of their potential application in fighting the forest fires in the Republic of Serbia were analyzed through the SWOT and the TOWS analyses, and appropriate strategies were defined and further developed with the most important elements.

# 2. Literature Review

## 2.1. Forest fires

The threat of forest fires is a major problem in many continents and countries all over the world, as forest fires can have devastating effects on human lives, but on the environment, and businesses, too. Forest fires, besides destroying huge areas of forest, present a serious threat to entire ecosystems, with huge effect on the future generations. Forest fires influence primarily cause destruction of forest ecosystems (Aydin, Selvi, Tao, & Starek, 2019). They destroy plant life and the habitations of numerous animal species. Flora and fauna often need a long time for recovering after a fire, and many species may be endangered or even extinct, like we saw in the case of huge forest fires in Australia. Woodland loss also decreases biodiversity and interrupts the natural balance of ecosystems (Yandouzi, et al. 2022).

Forest fires, which are often caused by climate change, can also have an impact on further climate change. Forest fires release vast amounts of carbon dioxide (CO2) and other greenhouse gases into the atmosphere, contributing even more to global warming. Forests are one of the main absorbers of CO2, and their destruction reduces the planet's capacity to absorb carbon and regulate climate change (Roldán-Gómez, González-Gironda, & Barrientos, 2021; De la Fuente, Aguayo, & Contreras-Bolton, 2024). Forest fires also have negative impact on air quality. Smoke and ash produced during wildfires significantly worsen air quality, often at great distances from the fires (Saffre, Hildmann, Karvonen, & Lind, 2022; Namburu, Selvaraj, Mohan, Ragavanantham, & Eldin, 2023). Bad air quality can cause respiratory problems in people, especially those with asthma, chronic lung diseases, and heart diseases. Longer periods of exposure to smoke can cause serious health problems for the entire population. The most vulnerable are the children, with or without previous respiratory problems.

After the destruction of a forest or forests, the soil is prone to erosion because there are no plants with the roots to hold the soil and prevent landslides. Water, especially possible floodwater and possible strong winds without difficulty carry away the upper layers of the soil, which reduces soil fertility. This can affect not only the woodland, but the neighboring agriculture land. This than negatively affects agriculture and in the long term deprive the soil of valuable minerals, making it less suitable for re-vegetation efforts. Forest fires can also have a negative impact on water supply, as they destroy foliage that helps in filtration and regulation of water flows (Saffre, Hildmann, Karvonen, & Lind, 2022). Affected water resources can be contaminated with ash and other chemical pollutant, which reduce the quality of drinking water and endangers local communities and the wildlife. After the wildwood is destroyed by fire, the region becomes more susceptible to new fires. Dry trees, remnants of shrubberies, and organic materials remain on the ground, creating extremely flammable elements. Such

areas can become more prone to future fires, making prevention and monitoring a key factor (Aydin, Selvi, Tao, & Starek, 2019; Roldán-Gómez, González-Gironda, & Barrientos, 2021; Buchelt, et al. 2024).

Forest fires can directly threaten human lives and destruction of property (Yandouzi, et al. 2022). Dry weather conditions and long term droughts, dry vegetation and rough winds can contribute to the speedy spread of the fire and may threaten wider areas than it would be the initial projection. Many communities near forests have to be evacuated, as it can be seen on the examples of California and Spain, and Greece, and houses, farms, factories, businesses and infrastructure are often destroyed) (Roldán-Gómez, González-Gironda, & Barrientos, 2021; Saffre, Hildmann, Karvonen, & Lind, 2022). In some cases, human lives have been lost due to the speed of a fire and unpredictable nature of the fire's spread. The economy of affected regions can be severely impacted by wildfires (Simoes, Rodrigues, Reis, & Sargento, 2020). Destruction of agricultural lands, forestry, and other industries, especially tourist capacities and infrastructure can lead to massive financial losses. Power lines, roads, and communication infrastructure may be destroyed, making normal life difficult in the affected areas (Saffre, Hildmann, Karvonen, & Lind, 2022).

Reconstruction of damaged areas is costly and can take years (Innocente, & Grasso, 2018), while firefighting costs are also a significant expense for local governments, which often have to plea for state funding (Akhloufi, Couturier, & Castro, 2021). Inhabitants sometimes chose not to return to destroyed areas due to difficulty of rebuilding lives and communities and due to trauma they went through. It is often neglected, but forest fires can have serious psychological effects on the people affected. Loss of property, evacuations and the constant fear of fire can cause stress, anxiety, and long-term mental health problems, sometimes survivors are later burdened with various psychosomatic disorders.

### 2.2. Implementation of UAS in fighting forest fires

The threat of forest fires is not restricted to local environmental destruction, it also includes a wide range of concerns that can affect human health, local and regional economy (sometimes states' economy too) (Laszlo, Ágoston, & Xu, 2018). Operative and efficient fire deterrence and management are crucial factors in reducing these risks, and advances in new technologies such as drones can provide assistance in timely detection and rapid response to fires (Krüll, Tobera, Willms, Essen, & Von Wahl, 2012; Cruz, Eckert, Meneses, & Martínez, 2016; Ausonio, Bagnerini, & Ghio, 2021; Zhang, Srivastava, & Eachempati, 2023). The implementation of drones in firefighting is becoming increasingly beneficial due to their effectiveness and ability to help firefighters and other local bodies in demanding and hazardous circumstances.

In recent decade, many researchers focused on various ways of drones' implementation in fighting forest fires:

- Prevention and risk assessment (drones used for monitoring areas prone to forest fires can detect early signs of fire or identify high-risk areas, enabling timely preventive actions) (Restas, 2015; Kinaneva, Hristov, Raychev, & Zahariev, 2019; Akhloufi, Couturier, & Castro, 2021; Nithyavathy, Kumar, Rahul, Kumar, Shanthini, & Naveen, 2021; Saffre, Hildmann, Karvonen, & Lind, 2022; Zhang, Srivastava, & Eachempati, 2023; De la Fuente, Aguayo, & Contreras-Bolton, 2024).
- Control and monitoring of fires (drones equipped with high-resolution cameras and infrared sensors can provide vital information about fire range, temperature and the precise sites mostly affected with fires) (Restas, 2015; Correia, Santos, Carvalho, & Martinho, 2020; Roldán-Gómez, González-Gironda, & Barrientos, 2021; Akhloufi, Couturier, & Castro, 2021; Ausonio, Bagnerini, & Ghio, 2021; Buchelt, et al. 2024; De la Fuente, Aguayo, & Contreras-Bolton, 2024). This information allows local authorities and firefighters to improve building their strategies, planning their actions, and allocating their resources more efficiently.
- Access to unapproachable areas (drones can fly over remote areas not easily accessible to firefighters) (Innocente, & Grasso, 2018; Akhloufi, Couturier, & Castro, 2021);
- Providing real-time data to appropriate bodies (drones can provide real-time data for local government, firefighters, and other emergency services) (Akhloufi, Couturier, & Castro, 2021; Yandouzi, et al. 2022).

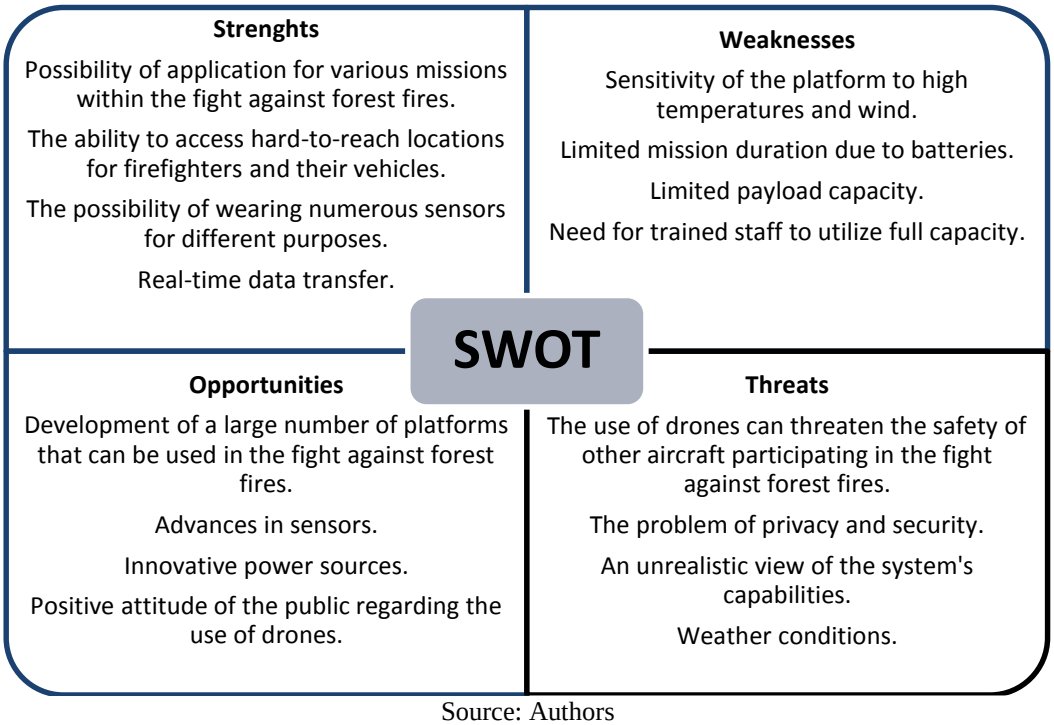
- Usage of thermal cameras (drones equipped with thermal cameras can detect hotspots that are not visible to the naked eye, helping to identify hidden fires or hot spots that could reactivate) (Kardasz, Doskocz, Hejduk, Wiejkut, & Zarzycki, 2016; Kinaneva, Hristov, Raychev, & Zahariev, 2019; Namburu, Selvaraj, Mohan, Ragavanantham, & Eldin, 2023).
- Delivery of equipment (drones can also be used to transport emergency equipment, such as fire extinguishers, medical supplies or even small amounts of extinguishing agents, directly to the field or to isolated areas affected by a fire) (Saffre, Hildmann, Karvonen, & Lind, 2022; Zhang, Srivastava, & Eachepati, 2023).
- Mapping (drones can produce detailed maps of the affected areas, facilitating assessing destruction levels and projecting future danger zones) (Ausonio, Bagnerini, & Ghio, 2021; Zhang, Srivastava, & Eachempati, 2023).

## 3. Results and Discussion

SWOT analysis (Strengths and Weaknesses represent internal factors, while Opportunities and Threats represent so-called external factors) is used to determine internal and external factors of developing strategies for implementation of drones in fighting forest fires in the Republic of Serbia. The TOWS matrix as a very useful analytical instrument that combines each SWOT component with another to analyze four alternative strategies: SO, WO, ST and WT (Huang, & Wei, 2024; Sammut & Bonnici & Galea, 2015; Ilić, Milošević, & Ilić-Kosanović, 2021) is than developed.

A thorough analysis of the factors of the external and internal environment based on the literature analysis, resulted in the SWOT matrix shown at Figure 1, which shows the strengths, weaknesses, opportunities and threats of implementation of drones in fighting forest fires in the Republic of Serbia.

Figure 1. SWOT analysis of implementation of drones in fighting forest fires in the Republic of Serbia.




Source: Authors

The factors acknowledged by the SWOT analysis are used to generate a TOWS matrix through which four alternative strategies SO1, WO1, ST1 and WT1 are generated. The alternative strategies are shown at Table 1.

Table 1. TOWS analysis of application of drones in fighting forest fires in the Republic of Serbia.

| **TOWS** | | **Strengths** | **Weaknesses** |
|---|---|---|---|
| | | $S_1$ Possibility of application for various missions within the fight against forest fires.<br>$S_2$ The ability to access hard-to-reach locations for firefighters and their vehicles.<br>$S_3$ The possibility of wearing numerous sensors for different purposes.<br>$S_4$ Real-time data transfer. | $W_1$ Sensitivity of the platform to high temperatures and wind.<br>$W_2$ Limited mission duration due to batteries.<br>$W_3$ Limited payload capacity.<br>$W_4$ Need for trained staff to utilize full capacity. |
| **Opportunities** | $O_1$ Development of a large number of platforms that can be used in the fight against forest fires.<br>$O_2$ Advances in sensors.<br>$O_3$ Innovative power sources.<br>$O_4$ Positive attitude of the public regarding the use of drones. | **SO Strategy** | **WO Strategy** |
| | | $SO_1$ Investing in the production of specialized drones for fighting forest fires. | $WO_1$ Improvement of the existing assemblies and drive unit of the drone. |
| **Threats** | $T_1$ The use of drones can threaten the safety of other aircraft participating in the fight against forest fires.<br>$T_2$ The problem of privacy and security.<br>$T_3$ An unrealistic view of the system's capabilities.<br>$T_4$ Weather condition. | **ST Strategy** | **WT Strategy** |
| | | $ST_1$ Improved situational awareness system. | $WT_1$ Public promotion of the results achieved by applying the system in the fight against forest fires. |

Source: Authors

Based on SWOT analysis, as shown at Table 1,TOWS matrix produced four fundamental strategies taking into the account, technological capacity of the Republic of Serbia for production of drones, improvement of technological capabilities of current units and of situational awareness system, and the raising the public awareness:

- $SO_1$ Investing in the production of specialized drones for fighting forest fires.
- $WO_1$ Improvement of the existing assemblies and drive unit of the drone.
- $ST_1$ Improved situational awareness system.
- $WT_1$ Public promotion of the results achieved by applying the system in the fight against forest fires.

For further development of strategies, the following key elements of any further strategy should be considered:

- Fire monitoring and supervision
    - Drones are enabling the monitoring large areas affected by fires (Restas, 2015; Ausonio, Bagnerini, & Ghio, 2021; Saffre, Hildmann, Karvonen, & Lind, 2022).
    - Equipped with high-resolution cameras and infrared sensors, they can provide accurate data on the spread of fire, direction of the wind, hot spots, and estimations of the area affected by the fire (Ausonio, Bagnerini, & Ghio, 2021; Akhloufi, Couturier, & Castro, 2021).
    - This information is vital for coordinating field actions and resource planning (Yandouzi, et al. 2022; Buchelt, et al. 2024).
- Prevention of forest fires

  - Systematic guarding of forest areas in order to identify first signs of fire (Ausonio, Bagnerini, & Ghio, 2021; Saffre, Hildmann, Karvonen, & Lind, 2022).
  - Uncovering of criminal actions, such as igniting fires or discarding various types of waste in forest areas (Hristov, Raychev, Kinaneva, & Zahariev, 2018).
  - Observing of the state of vegetation and discovery of dry areas that represent a high risk of fire (especially during the summer or long periods of draughts) (Roldán-Gómez, González-Gironda, & Barrientos, 2021; Yandouzi, et al. 2022).
- Role in creating public awareness
  - Drones allow the media and public institutions to collect images and videos of wildfires, which are later used to educate the public about the severity of fires, risks, and precautions and to assist in creating awareness about precautionary measures (Roldán-Gómez, González-Gironda, & Barrientos, 2021), as the awareness in Serbia is not on the desired level.
- Drone fire extinguishing system development
  - Even though this technology is still under development, there are efforts to develop drones capable of active firefighting especially at the early stages of a fire (Nithyavathy, Kumar, Rahul, Kumar, Shanthini, & Naveen, 2021; Saffre, Hildmann, Karvonen, & Lind, 2022). The Republic of Serbia has capabilities, both in technology and in human capital competencies to develop those systems.

## 4. Conclusion

Drones have become an essential instrument in modern approach to forest fire management based on new technologies, namely information technologies, and artificial intelligence. Their ability to deliver fast and correct data makes them vital to firefighting efforts around the world. As technology advances, it is expected that the use of drones will become even more widespread and contribute to more effective suppression of forest fires, which will reduce both environmental and economic damage. It is the same for the Republic of Serbia efforts in fighting the forest fires. This paper set the basic strategy for the Republic of Serbia which includes fundamental steps in using drones for fighting forest fires. Consequently, new strategies for fighting forest fires have to include plans for introducing and implementing drones as key elements of firefighting efforts.

In further development of the strategies, it should be taken into the account that drones reduce the risk for firefighters, allowing them to get detailed information and access to areas that would be too dangerous for humans. The use of drones against forest fires is becoming a key innovation in modern emergency management. Wildfires often cover large areas and can spread quickly, making traditional firefighting methods ineffective or dangerous. Drones, given their flexibility and advanced technologies, significantly contribute to the fight against these disasters.

## Literature

1. Akhloufi, M. A., Couturier, A., & Castro, N. A. (2021). Unmanned aerial vehicles for wildland fires: Sensing, perception, cooperation and assistance. *Drones*, *5*(1), 15.
2. Ausonio, E., Bagnerini, P., & Ghio, M. (2021). Drone swarms in fire suppression activities: A conceptual framework. *Drones*, *5*(1), 17.
3. Aydin, B., Selvi, E., Tao, J., & Starek, M. J. (2019). Use of fire-extinguishing balls for a conceptual system of drone-assisted wildfire fighting. *Drones*, *3*(1), 17.
4. Buchelt, A., Adrowitzer, A., Kieseberg, P., Gollob, C., Nothdurft, A., Eresheim, S., ... & Holzinger, A. (2024). Exploring artificial intelligence for applications of drones in forest ecology and management. *Forest Ecology and Management*, *551*, 121530.
5. Correia, A., Santos, L. A., Carvalho, P., & Martinho, J. (2020). The use of unmanned aerial vehicles in the monitoring of forest fires. In *Advances in Natural Hazards and Hydrological Risks: Meeting the Challenge: Proceedings of the 2nd International Workshop on Natural Hazards (NATHAZ'19), Pico Island—Azores 2019* (pp. 75-79). Springer International Publishing.
6. Cruz, H., Eckert, M., Meneses, J., & Martínez, J. F. (2016). Efficient forest fire detection index for application in unmanned aerial systems (UASs). *Sensors*, *16*(6), 893.

7. De la Fuente, R., Aguayo, M. M., & Contreras-Bolton, C. (2024). An optimization-based approach for an integrated forest fire monitoring system with multiple technologies and surveillance drones. *European Journal of Operational Research*, *313*(2), 435-451.
8. Hristov, G., Raychev, J., Kinaneva, D., & Zahariev, P. (2018). Emerging methods for early detection of forest fires using unmanned aerial vehicles and lorawan sensor networks. In *2018 28th EAEEIE annual conference (EAEEIE)* (pp. 1-9). IEEE.
9. Huang, T., & Wei, J. (2024). Management strategies for museum night opening in China: a SWOT-TOWS analysis of Shanghai museums. *Cogent Social Sciences*, *10*(1), 2327857.
10. Ilić, D., Milošević, I., & Ilić-Kosanović, T. (2022). Application of Unmanned Aircraft Systems for smart city transformation: Case study Belgrade. *Technological Forecasting and Social Change*, *176*, 121487.
11. Ilic, D., Milosevic, I., & Ilic-Kosanovic, T. (2021). Application of unmanned aircraft systems for disaster management in the Republic of Serbia. *Fresenius Environmental Bulletin*, *30*(7 A), 9580-9595.
12. Innocente, M. S., & Grasso, P. (2018). Swarms of autonomous drones self-organised to fight the spread of wildfires. In *RSFF 2018 Robust Solutions for Fire Fighting: GEOSAFE Workshop on Robust Solutions for Fire Fighting* (pp. 30-39). CEUR.
13. Kardasz, P., Doskocz, J., Hejduk, M., Wiejkut, P., & Zarzycki, H. (2016). Drones and possibilities of their using. *J. Civ. Environ. Eng*, *6*(3), 1-7.
14. Kinaneva, D., Hristov, G., Raychev, J., & Zahariev, P. (2019). Early forest fire detection using drones and artificial intelligence. In *2019 42nd International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)* (pp. 1060-1065). IEEE.
15. Krüll, W., Tobera, R., Willms, I., Essen, H., & Von Wahl, N. (2012). Early forest fire detection and verification using optical smoke, gas and microwave sensors. *Procedia Engineering*, *45*, 584-594.
16. Laszlo, B., Ágoston, R., & Xu, Q. (2018). Conceptual approach of measuring the professional and economic effectiveness of drone applications supporting forest fire management. *Procedia engineering*, *211*, 8-17.
17. Namburu, A., Selvaraj, P., Mohan, S., Ragavanantham, S., & Eldin, E. T. (2023). Forest fire identification in UAV Imagery using x-mobilenet. *Electronics*, *12*(3), 733.
18. Nithyavathy, N., Kumar, S. A., Rahul, D., Kumar, B. S., Shanthini, E. R., & Naveen, C. (2021). Detection of fire prone environment using Thermal Sensing Drone. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1055, No. 1, p. 012006). IOP Publishing.
19. Restas, A. (2015). Drone Applications for Supporting Disaster Management. *World Journal of Engineering and Technology*, 3, 316-321. doi: 10.4236/wjet.2015.33C047.
20. Roldán-Gómez, J. J., González-Gironda, E., & Barrientos, A. (2021). A survey on robotic technologies for forest firefighting: Applying drone swarms to improve firefighters' efficiency and safety. *Applied sciences*, *11*(1), 363.
21. Saffre, F., Hildmann, H., Karvonen, H., & Lind, T. (2022). Monitoring and cordoning wildfires with an autonomous swarm of unmanned aerial vehicles. *Drones*, *6*(10), 301.
22. Sammut- Bonnici, T., & Galea, D. (2015). *SWOT analysis.* Wiley Encyclopedia of Management, 1-8.
23. Simoes, D., Rodrigues, A., Reis, A. B., & Sargento, S. (2020). Forest fire monitoring through a network of aerial drones and sensors. In *2020 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops)* (pp. 1-6). IEEE.
24. Yandouzi, M., Grari, M., Idrissi, I., Boukabous, M., Mous-saoui, O., Azizi, M., ... & Elmiad, A. K. (2022). Forest fires detection using deep transfer learning. *Forest*, *13*(8), 1.
25. Zhang, J. Z., Srivastava, P. R., & Eachempati, P. (2023). Evaluating the effectiveness of drones in emergency situations: a hybrid multi-criteria approach. *Industrial Management & Data Systems*, *123*(1), 302-323.