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Logistics challenges of approaching the wildfires with different fire vehicles

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Abstract

In order to protect human life, property and the environment from wildfires, professional and voluntary fire departments are the first interveners in Hungary. One of the major challenges of firefighting against wildfires is the logistics. Such a logistic challenge is the migration to the fire site with different fire vehicles. The logistic challenges of wildfires usually developed in rural areas, on dirt roads of the forest, away from the residential areas. These areas are difficult to approach with some fire trucks that are not specifically designed for these purposes. These difficulties affect the efficiency of firefighting. In the paper, the Author draw conclusions from the logistical difficulties of firefighting against wildfires that are suitable for proving the time loss of migration and to determine how the time loss affects the spread of a fire and the effectiveness of firefighting. The Author shows how the frontline ($T_{frontline}$) of a fire can change due to time loss (Δt) at 1 m/min, 5 m/min and 9 m/min fire propagation ($V_{fire\ propagation}$). By using a formula, the Author also calculate the size of frontline fire. As a result of the paper he determines the amount of time loss with a new method, which is related to the increase of fire frontline.

1. Introduction

According to The Global Risks Report 2022 created by the World Economic Forum, for the next five years, respondents again signal societal and environmental risks as the most concerning. However, over a 10-year horizon, the health of he planet dominates concerns: environmental risks are perceived to be the five most critical long-term threats to the world as well as the most potentially damaging to people and planet, with “climate action failure”, “extreme weather”, and “biodiversity loss” ranking as the top three most severe. (WEF 2022). Climate change is a challenge in many areas of science, society and life, so it also has an impact on the disaster management. The above mentioned climate change factors provide a greater opportunity to ignite the combustible fuel, which increases the risk of wildfires. The wildland as a natural area carries many social values in itself, so we protect it from fires (Almeida 2021).

Firefighting is often a long and complex process (Figueras 2015), the main stages of it is to stop the fire spread, to eliminate the flames and to supress the fire. In the process, firefighters face a huge number of logistical challenges (Jain 2020). Several researchers have investigated the logistic difficulties of firefighting. (Rácz, 2016), (Bodnár, 2016). The first deep investigation in the topic was carried out by (Restás 2003) in Hungary, who examined the effectiveness of increasing the number of firefighting interventions with a value - time function, but he also analysed the time elapsed during the steps of firefighting, the network of logistics bases and their distance. Other research focuses on threat of forest and vegetation fires and the possibilities of intervention (Bodnár 2019), and the forest fire detection (Bodnár 2018).

2. Methods

In order to achieve the research objectives, I studied the most important national and international literatures focusing on the topic of the logistics of firefighting. In addition, I have had personal consultations with various experts and participated in international scientific conferences and study tours. I presented my logical conclusions and results using histograms and diagrams. In illustrating the logistics problems, I made schematic diagrams and explanatory drawings, the analysis of it helped me to understand the mathematical foundations of my efficiency analysis. During the logistic challenges of firefighting, I examined the effects of time loss caused by migration on poor quality roads. I also took pictures of poor quality roads on my observation plot (Figure 1).

Figure 1- Poor quality dirt roads in the forest, nearby a water source in Hungary.

In addition, I examined the extent and impact of time loss, caused by migration to the fire site on poor quality dirt roads. For my research, I edited a conceptual Figure (Figure 2) which shows how far a fire truck can travel on different types of roads in a given amount of time. I did not simply characterize the problem of time loss during marching, but I first related it to the increase in length of the burnt fire frontline.

To investigate the approach of fire site, I established my assumptions based on the experiences of drivers of fire trucks. According to drivers and relevant national legislations, a fire truck has an average speed of 60 km /h on driveway and an average speed of 20 km/h on dirt roads (Decree, 2011). The average speed of 20 km / h on dirt road is a third of the speed on a driveway, so there is a logical proportionality between the two values. Consequently, I consider the two values to be acceptable and authoritative during the research. After determining the speed of the fire trucks, I also have to assume a migration time. The average time to approach a fire site with fire trucks is 15 minutes in the European Union is (Müller, 2020). Based on my own analysis, the Hungarian fire brigades cannot yet fulfilling this in all cases, so during my research (schematic figure) I expect an intervention time of 20 minutes. Areas in literatures refer to so-called white spots as areas that are not approachable from a professional fire brigade during the specified 25-minute migration period (Berczi and Papp 2017). This time is an upper limit, so I consider the 20-minute long marching time I have chosen to be logically acceptable.

For my research, I edited a schematic figure (Figure 2), which shows how far a fire truck can travel on different types of roads. In the figure, the vertical axis indicates each route possibilities and how many km the fire truck can travel on a driveway. The horizontal axis shows the travel on dirt roads for the remaining time. The green line indicates the distances reached within 20 minutes (reality). The red line indicates the distance of 20 km (goal). The area between the green and red lines gives the difference in efficiency (Time loss).

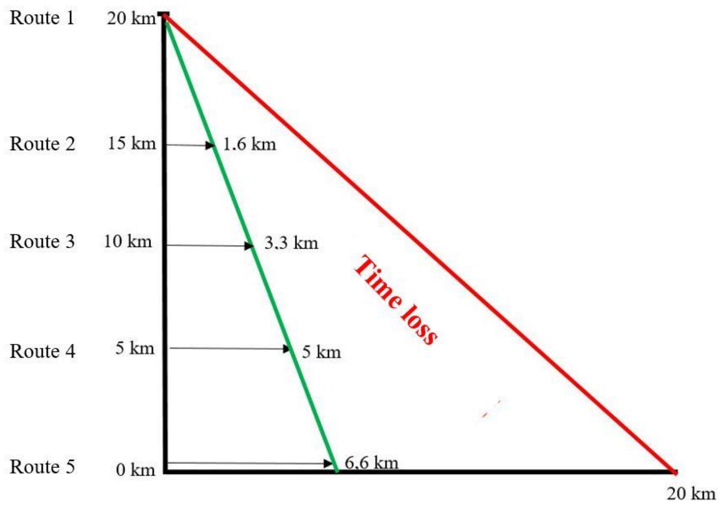

Figure 2- Schematic figure of different migration route combinations.

On *Route 1*, the approach of fire site is entirely on driveway with a speed of 60 km / h (in 20 minutes), so the maximum distance that a fire truck can be covered is 20 km. I consider it to be the most favorable condition. On *Route 5*, fire truck travels along the dirt road (with a speed of 20 km / h), so it cannot cover the distance of 20 km, only a fraction of it, which is 6.6 km. I consider it to be the most unfavorable condition. Of course this case is only a logical assumption, as all fire stations are located so as to be approach on driveways. The Figure also proves the logical conclusion that the more a fire truck travels on a dirt road, the less distance it takes in 20 minutes. I have plotted five different hypothetical route options.

I have already analyzed the best and the worst route options (Route 1 and 5), for the other routes traveled the distances change as follows. In Route 2, site approach will take place on a 15 km driveway and then on a 1.6 km dirt road (which would be 5 km on a driveway). This ratio is already 10 km - 3.3 km in Route 3 and 5 km - 5 km in Route 4. Figure 2 demonstrate my logical assumption that the site approach on a dirt road results in a significant time loss, which affects the effectiveness of firefighting. Table 1 illustrates the traveled distance in km (in 20 minutes) in six routes options. In addition, I also calculated the average speed of the fire truck on the different route options.

Table 1 - Approach to the fire site on different types of routes. Created by the author.

Approach to the fire site on different types of routes			
Routes	**Traveled distance (km)**	**Average speed**	**Elapsed time**
1.	20	60 km/h	20 min
2.	16,6	50 km/h	20 min
3.	13,3	40 km/h	20 min
4.	10	30 km/h	20 min
5.	6,6	20 km/h	20 min

In case of wildfires, fire trucks sometimes travel long distances on narrow dirt roads in order to approach a fire site, which is a significant time loss in terms of firefighting. This happened in Hungary in case of large fires in the Southern Great Plain (Kaskantyú, Törtel). Case studies have also been prepared on this topic (Bodnar, 2017). In the next chapter I will examine how much the length of the frontline fire increases as a result of the time loss.

3. **Results**

After the analysis of the site approach, I calculated (Table 2) how the frontline ($T_{frontline}$) of a fire can change due to time loss (Δt) at 1 m/min, 5 m/min and 9 m/min fire propagation ($V_{fire\ propagation}$). By using the bottom formula, I also calculate the size of frontline fire (conditions: homogeneous wildland fuel, calm wind, flat terrain).

$$T_{frontline} = 2x\Delta tx\ v_{fire\ propagation}\ x\ \pi \qquad (1)$$

Table 2 - Changes in the frontline of fire during different fire propagations.

Changes in the frontline of fire during different fire propagations					
Time loss (min)	0	10	20	30	40
1 m/min	0	63	126	188	251
5 m/min	0	314	628	942	1 256
9 m/min	0	556	1 130	1 696	2 261

I would like to note that, from the modelling point of view of, fire propagation can only be characterized by a circular shape on flat terrain in case of homogeneous fuel and calm winds, in all other cases the ellipse shape should be considered as dominant (Rothermel, 1972). However, at ellipse, the increase in circumference is not linear but larger than in case of circle, so this proves my conclusion. In Table 2 I rounded my results for a more comprehensible illustration. As a result of Table 2, I conclude that, on the one hand, the longer the travelled distance decreases in 20 minutes, the more time loss will be (it makes sense). On the other hand, the more is time loss, the longer the length of the fire frontline will be. To illustrate my conclusion, I created Figure 3, where I illustrate the relationship between time loss and the increase in fire frontline at the fire propagation speeds (1 m/min, 5 m/min, 9 m/min) examined above. It is clear from the graph that as the lower velocity section increases, the length of the unnecessarily increasing frontline changes linearly.

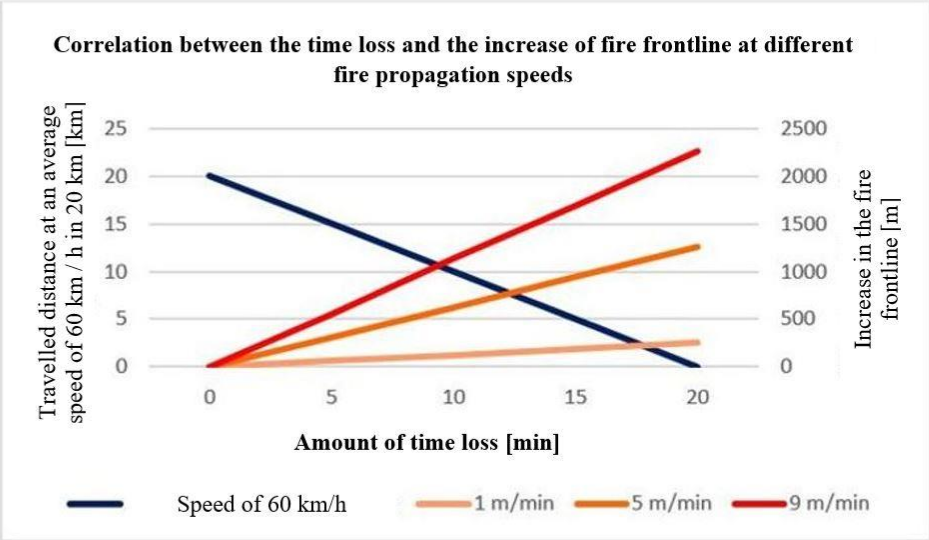

Figure 3 - Correlation between the time loss and the increase of fire frontline at different fire propagation speeds. Created by the Author.

Poor terrain conditions reduce the effectiveness of firefighting not only during site approach but also later during the constant water supply. However, this condition also helps the fire to spread further. In order to protect the built environment and residential areas it is unavoidable to move fire trucks in the field. In addition, I analysed the pros and cons of the use of an Extinguisher water backpack, an All-terrain vehicle (ATV), a Pick up and a Fire truck during the firefighting. By comparing the effectiveness of vehicles, I determined what types of interventions they could be used efficiency. I based my analysis on the approach to fire site, on the following types of routes: paved road, good quality dirt road, poor quality dirt road, forest path, forest trail, forest.

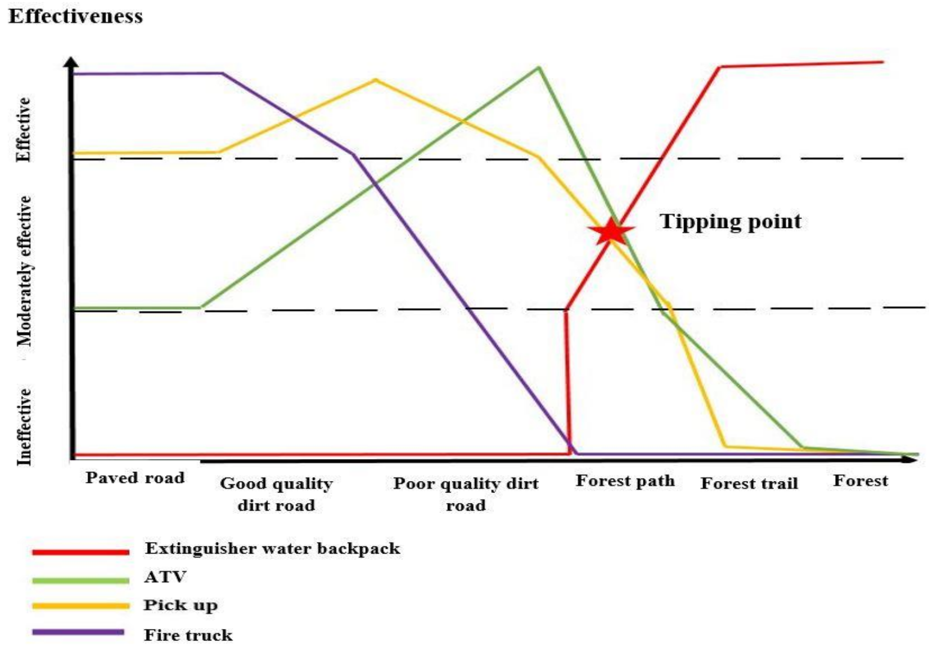

Figure 4- Illustration of logistical efficiency of vehicles and equipment on different types of roads.

Based on Figure 4, I found that as long as we can approach the fire site easily, the use of fire trucks is effective. However, this is changing as we move towards into the interior of wildland, where smaller vehicles like Pick up and ATV are a more effective solution, mainly because of their good off-road capability. I considered forest path to be tipping points in the efficiency of site approach, as this is the point where use of large fire trucks is no longer effective. On these types of routes, smaller firefighting vehicles are more effective.

4. Conclusion

As a result of my analysis of route combinations, I came to the conclusion that site approach on the dirt road results in time loss. As a result of it, interveners start firefighting at the fire site late. This also affects the lengths of the fire frontline, making the efficient firefighting more difficult. Intervention in time will also help save lives, and amount of damage will be less due to the shorter migration time. After examining the approach problem of fire site, my logical conclusion is that a calculation of time loss of migration should be made. In addition, it would be useful to widen and improve the quality of several dirt roads in the forest, in order to make these routes more walkable in case of a wildfire, thus reducing time loss. In many cases, fire site is covered with a large amount of reeds or grass, so much of the burned area can only be approached with the help of local people. Orientation can also be made with geographic information system (GIS), but in many cases this is not real-time and needs to be regularly updated (Burrough; Mc Donnel, 1998).

From logistical difficulties of fighting against wildfires, I drew conclusions that are suitable for detecting the time loss of migration and for establishing new methods and tools. Within this framework, I have dealt with effects of time loss caused by migration on poor quality roads. I not only characterized the problem of late arrival with time, but I related it to the increase in length of the fire frontline. To understand and illustrate this problem, I created a self-edited figure. Next, I analyzed advantages and disadvantages of an extinguisher water backpack, a firefighting ATV, a pick up, and a fire truck during the firefighting. By comparing the efficiency of vehicles, I determined what types of interventions they can be used efficiency. This was based on one of the most important factors in efficiency of vehicles, which is the approach to fire site. Consequently, I have concluded that, as long as we can approach the fire site easily, the use of large and high-capacity vehicles is effective. However, this changes as we move towards into the interior of the forest, the smaller vehicles are more effective because of their good off-road capability. I consider the forest path as a tipping point in the application efficiency between large and small vehicles.

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