MEASURING THE EFFICIENCY BY MIXING THE COSTS AND THE EFFECTIVENESS OF EXTINGUISHING MATERIALS AND AERIAL FIREFIGHTING

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ABSTRACT
Introduction: Aerial firefighting is known to be a very costly firefighting technique, which encourages professionals to investigate its effectiveness and to be aware of the influential factors as well as to strive to find a way to reduce costs and increase efficiency prior to making a decision. Method: examination is basically based on mathematical calculations, comparative analyses and proportioning. Simple charts and graphs help to evaluate the findings and to explain and illustrate the relationship between them. Among the research methods, logical deductions and the application of practical experience can be found. Results: the research introduces a new method of examining the effectiveness of aerial firefighting, which helps to conduct analyses and comparisons based on real data. This method contributes to a better understanding of key factors affecting effectiveness, gives guidance on the possible ways to increase effectiveness, their potentials and limitations.

KEY WORDS: *aerial firefighting, professional effectiveness, economic efficiency, absolute index, standard index, comparative index, vertical and horizontal divisions, matrix analysis*

1. Introduction

The success and effectiveness of aerial firefighting is influenced by many factors. It would be a complex and complicated task, if not impossible, to evaluate all of them. Despite this, the author picked a few basic factors which have considerable impact on the economic efficiency of aerial firefighting. One of them is the extinguisher itself together with its extinguisher ability. It certainly varies from extinguisher to extinguisher. The promotion materials of different companies selling extinguishers clearly demonstrate these differences, by highlighting the unique, beneficial feature of the given extinguisher.
The other basic factor is the cost of the transportation of the extinguishers to the scene or with other words, its efficiency. If we accept that there are differences in the extinguisher ability, we must conclude that the more effective extinguishers are worth being used despite the higher transportation costs. The extent of the efficiency of the latter factor is influenced by not only the transportation costs but the costs of the extinguisher itself. The author studies the correlation between the above factors.

2. The effectiveness of the extinguishers and related expenses

We know several methods of examining the effectiveness of extinguishers. Some of them are generally accepted and standardised in certain countries, e.g. LIFT[1], TM2[2] methods, while others are merely used for the purposes of researches (Batista, 2011; Fiorucci, 2011a; Fiorucci, 2011b; Morris, 2011). The effectiveness of the extinguisher is shown by the way it puts out a fire, that is, how it is able to reduce the speed of fire spread (v_0) or

[1] LIFT – Lateral Ignition and Flame Spread
[2] TM2 – Test Method 2 Combustion Retarding Effectiveness Test

even stop it (v_x; $v_x<v_0$, or $v_x=0$). Obviously, the latter is the final solution, but with most methods, their ability to reduce the speed of spread is considered a sign of their effectiveness (e.g. LIFT). The author accepts the previous method to analyse this topic, that is, an extinguisher is considered effective not only if it extinguishes the fire completely but also if it reduces the speed of fire spread. In the end, the steady reductions of the speed results in stopping the fire spread or, in other words, complete extinguishment. As a result, the effectiveness of extinguishers reducing the speed of fire spread to varying extents is different, too. Obviously, the more it reduces the speed of fire spread, the more effective it is.
The varying abilities to extinguish a fire must be accompanied by further differences, so the expenses are most likely to be dissimilar. Provided that we accept the previous statement, that is, not only the total extinguishment of the fire is effective, but also the reduction of the speed of fire spread, then professional effectiveness depends on the extent of speed reduction. Professional effectiveness considers significant only the goal, which is in this case the higher extent the extinguisher reduces the speed of fire spread. The resources used and the expenses are, however, ignored (Restas, 2011). Extinguishers reducing the speed of fire spread by the same extent are assessed as having the same professional effectiveness, irrespective of the expenses they incur.
The most general extinguisher is water. Its cost is so insignificant compared to other extinguishers that it is often overlooked. Water is not only used by itself but to produce other extinguishers like retardants or foams. If we disregard the cost of water, the cost per unit of extinguishers depends on two factors: mixing rate of the agent (R_{foam}) and the price of one unit of the agent (p_{foam}).

$$c_{foam} = R_{foam} p_{foam} \qquad (1)$$

In the case of advanced foams, the prescribed mixing rate is 0.5-3%, which means that 5-30 litres of concentrate is needed to make 1 m^3 solution. This solution produces 6-12 m^3 foam, which stops or reduces fire spread by covering the vegetation. The extinguisher ability of foams is naturally a combination of several factors, e.g. separation, isolation, cooling effects.
Identical extinguisher abilities may be characterised by expanditure rate as well, in the case of foams; in the example above this value is 6-12 ($R_{exp\ foam} = 6÷12$). Certainly, other features are also important, but expanditure rate is generally regarded as a feature indicating the initial extinguishing ability of the foams. Foam of low expanditure (high foam density) will stream down to the ground – like Newtonian fluid – instead of staying on the vegetation, thus it will not take part in effective extinguishment. Conversely, foam of high expenditure (low foam density) can be blown away by airflows.
If both the cost per unit and the extent to which it is able to reduce the speed of fire spread are dissimilar, then – assuming linear change – the ratio between them and its scale determine which extinguisher is more efficient economically. In this study, the author presumes that the effect resulting from the changing prices of the extinguishers and the related effect on the speed of fire spread (affecting effectiveness) is a linear variable.

3. The analysis of the extinguishers' effectiveness

Evidently, we need to take into account the different types of extinguishers and we had better start with the simplest one. The most general extinguisher is water, it is often used by itself, but it can also be mixed with retardants or foam-forming substances. The additives, obviously, are aimed at increasing the effectiveness of extinguishing with water, so they are more effective. As a result, it is logical to start with water and use it as a reference point. This is the simplest solution, which often succeeds in reducing the speed of fire spread ($v_w<v_0$) by itself. In terms of professional effectiveness, it represents one of the extreme values (the starting value) in the above range.
If we use retardants or foam-forming substances, we have to compare their ability to reduce the speed of fire spread to that of the water and to each other's (e.g. v_A, v_B). When comparing them to water – whether we look at the retardant or the foam –, professional effectiveness must be higher, since in the opposite case it would not make sense to waste resources on them.
The goal of extinguishers is to put out the fire or to reduce the speed of its spread. The extent of the reduction ($v_0 \rightarrow v_x$) is obviously correlated to the initial speed of fire spread (v_0). When comparing the different values of professional effectiveness, it reasonable to use the most simple extinguisher's, the water's effect as a starting point, that is, to what extent it is able to reduce the speed of fire spread; then compared to this value, the effects of the other extinguishers can be ranked. The author examined two different extinguishers (foam) in the experiment without naming them so that it does not harm the producers' interests (foam "A" and foam "B").

Different extinguishers are very likely to reduce the speed of fire spread by different extents. The difference between the speeds of fire spread measured at places treated (v_x) and not treated (v_0) with extinguishers can be determined simply by deducting one from the other, so the results can be ranked.

$$v_W = v_0 - v_1 \quad (2)$$

$$v_A = v_0 - v_2 \quad (3)$$

$$v_B = v_0 - v_3 \quad (4)$$

$$v_0 > v_1 > v_2 > v_3 \quad (5)$$

Ranking the above figures:

$$v_W < v_A < v_B \quad (6)$$

We can conclude from the above that they do help to determine the ranking of professional effectiveness, but actually they cannot provide guidance in comparing neither their relative effectiveness nor their economic efficiency.

4. Indexes describing the extinguishers' effectiveness

In order to determine effectiveness more precisely, we can make calculations using different factors, whose results can be used as indexes.

4.1. Absolute index

We get absolute index (Y_x) if we correlate the extinguishers' effect to reduce the speed of fire spread to the initial speed of the fire.

$$Y_W = \frac{v_0 - v_W}{v_0} = 1 - \frac{v_W}{v_0} \quad (7)$$

Based on the above the absolute indexes of the three extinguishers (water, foam "A", foam "B") are the following:

$$Y_W = 1 - \frac{v_W}{v_0} \quad (8) \qquad Y_A = 1 - \frac{v_A}{v_0} \quad (9) \qquad Y_B = 1 - \frac{v_B}{v_0} \quad (10)$$

The absolute indexes provide guidance on the extent by which the different extinguishers are able to reduce the speed of fire spread. Its value may be 1 or lower than 1; in the first case, the extinguisher not only slowed down fire spread but extinguished it completely. The closer the result is to 1, the slower the fire spread became, and in other words, the more effective the given extinguisher is. As a matter of logic, the other extreme value is possible as well. Thus, when $Y_x=0$, the extinguisher failed to reduce the speed of fire spread.

4.2. Standard index

The professional effectiveness of extinguishers can be expressed in other ways, too. The reduction of the speed of fire spread can be correlated not only to the initial speed of fire spread but also to the effect of the reference extinguisher. The author calls it standard index (Z_x). By correlating them to water, the simplest extinguisher, it becomes apparent how the professional effectiveness of the other extinguishers vary – affected by the additional costs, the expenditure. In terms of professional effectiveness, it is a more accurate guidance, as it does not compare the extinguisher directly to the fire but to the reference point, to water (having the lowest cost).

$$Z_A = \frac{Y_A}{Y_W} \quad (11), \text{ and} \qquad Z_B = \frac{Y_B}{Y_W} \quad (12)$$

Obviously, values higher than 1 are acceptable in the above case. If the value is 1, it shows that using additives in water does not result in increased effectiveness, so the resources spent on them were wasted. The higher the value is or the farther it is from 1, the more effective the extinguisher is.

4.3. Comparative index

Following the idea above, we can get the relative difference between the effectiveness of the two different extinguishers by using relation. This is the comparative index (G), the ratio of the standard indexes of the two different extinguishers to be compared.

$$G = \frac{Z_B}{Z_A} \quad (13)$$

The result shows the relation between the professional effectiveness of the two extinguishers. The farther its value is from 1, the bigger the difference is between the effectiveness of the two extinguishers. If the value is 1, there is no difference the professional effectiveness of the two extinguishers.
It does not affect our calculations which data (feature) we use as divisor or dividend. Naturally, we get a higher quotient by dividing the higher value, so that extinguisher is more effective professionally.

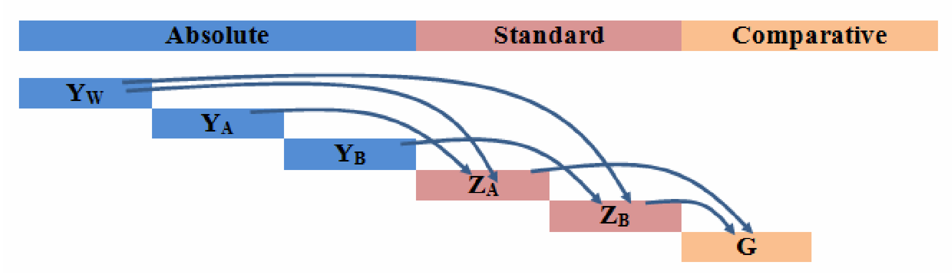

Figure 1 – Logic of the indexes of the professional effectiveness of the extinguishers

Based on the above, we determined the professional effectiveness of particular extinguishers, but we do not know how much a unit of them costs. We need to answer it later on. The relationship between the indexes of the professional effectiveness of the extinguishers is depicted in Figure 1.

5. Effectiveness of the logistic – costs of aerial firefighting

After the examination of the professional effectiveness of the extinguishers, the following questions arise: How is the given extinguisher transported to the frontline? How much does it cost? Its logistics is conducted by air transportation (aerial firefighting), which is known to be very costly. The cost analysis of this logistics task raises the issue of economic efficiency, which, by itself, still shows only professional effectiveness, as we will see.
The cost of aerial firefighting consists of several parts: the operation of the aircraft as well as the price of the extinguisher used. According to the author, it is a common mistake that the two are often dealt with separately, which might lead to false conclusions. It will be demonstrated later on. When assessing the economic efficiency of the extinguishment, it is imperative to treat both of them together.
Provided the costs of the aircraft are constant and we calculate with a definite amount, then the efficiency of aerial firefighting depends on the price of the extinguisher and its extinguishing effectiveness.
The operation cost per unit (c_{aff}) is decisive in the cost per unit of the aircraft (c_{AFF}), that is, the efficiency. Besides this, we also have to take into account the transport capacity of the aircraft (Q_{aff}) and in a given unit of time how many turns or deliveries it can carry out (n_{aff}), that is, what is the cost of transporting a unit of extinguisher to the fire front.
Following the above idea, we need the following information to calculate effectiveness (with sample:

- The cost of the aircraft in an hour: (=1000 €h^{-1})
- The transport capacity of the aircraft: (=1000 kg)
- The number of turns (deliveries): (= 10 h^{-1})

The transport cost of one unit of extinguisher can be calculated in the following way using the data above:

$$c_{AFF} = \frac{c_{aff}}{Q_{aff} n_{aff}} = (0.1 \text{€kg}^{-1}) \quad (14)$$

Similarly to the principles applied in the assessment of the professional effectiveness of the extinguishers, the transportation costs (aerial firefighting) need to be ranked as well. Water is applied in many cases, but its cost is rarely taken into account or not at all (e.g. from lakes, the sea), so in fact, only the costs of the aircraft are looked at, they dominate. The above suggests that this case ought to be viewed as the starting point or reference point. Regarding the costs, it represents one of the extreme values of the above range.

If we use retardants or various foam-forming substances, beside their effect of reducing the speed of fire spread, we also have to consider their related costs. In this case, the operation cost of the aircraft (14) and the cost of the extinguisher (1) together make up the total cost.

In the simplest case, we need to consider only the costs related to water. Based on the above, its reason is that the cost of water as an extinguisher is not regarded at all or only as a minimal amount ($C_w \approx 0$). Thus, we only have to calculate with the operation cost of the aircraft. In order to make the comparison simpler, it is reasonable to discuss the cost of one unit of the extinguisher (c_{AFF}).

It follows from the above that in the case of two aircrafts with identical operation costs – and other conditions also being identical, – that one is more efficient which is able to deliver more extinguisher to the scene within a given time. If the amounts are the same, the aircraft with lower cost can be viewed as more efficient. To determine the latter, the costs of the given extinguisher have to be specified; the data required to do so:

- The required mixing rate of foam "A": 3 %
- The price of foam-forming substance "A": 6 €kg^{-1}
- The required mixing rate of foam "B": 3 %
- The price of foam-forming substance "B": 12 €kg^{-1}

Calculating the costs of the two extinguishers with the help of the form (1):

$$c_A = R_A p_A = 0.018 \text{ €kg}^{-1} \text{ (15), and } c_B = R_B p_B = 0.036 \text{ €kg}^{-1} \text{ (16)}$$

6. Indexes describing the aerial firefighting's effectiveness

Similarly to the indexes of the professional effectiveness of the extinguisher, those of the aerial firefighting can be specified, too. In the following section, these calculations will be presented, illustrated with examples.

6.1. Absolute index

Based on the above water can be regarded as the reference point. Now mostly, the operation costs of the aircrafts are taken into account, while with the other extinguishers we need to add the costs of the extinguishers as well. This is the absolute index (C_x):

$$C_W = \frac{c_{AFF}}{c_{AFF} + c_W} \cong 1 \quad (17)$$

Based on the above, the formulas to determine the costs of the extinguishers can be constructed:

$$C_W = \frac{c_{AFF}}{c_{AFF} + c_W} \quad (18) \qquad C_A = \frac{c_{AFF}}{c_{AFF} + c_A} \quad (19) \qquad C_B = \frac{c_{AFF}}{c_{AFF} + c_B} \quad (20)$$

The cost of the water is not ignored. The author determined its value arbitrarily to be 5% of the operation cost of the aircraft.

The absolute index correlates the total cost of the extinguisher used to the cost per unit of the aircraft. Then, according to the values we get, the logistics methods can be simply ranked, which is about professional effectiveness strictly in terms of the expenses. Without the effectiveness of the extinguisher, this is not a relevant economic analysis either.

Its value can be 1 or less than 1; in the former case we do not look at the cost of the extinguisher (water), while in the latter one we do. The closer the value is to 1, the lower the cost of the extinguisher itself relative to the cost per unit of the aircraft.

6.2. Standard index

Similarly to the professional effectiveness of the extinguishers, the standard indexes of the logistic (U_x) can be created, too. In this case we correlate the cost per unit of the different extinguishers to that of the water. Then we get the quotient of the cost of the extinguisher and that of the water, as a reference cost.

$$U_A = \frac{R_A p_A Q_{aff} n_{aff}}{c_{aff}} = \frac{C_A}{C_W} \quad (21)$$

The formula for the two extinguishers:

$$U_A = \frac{C_A}{C_W} \quad (22), \text{ and} \qquad U_B = \frac{C_B}{C_W} \quad (23)$$

The above offer us a more accurate guidance in the effectiveness of logistic, because they do not correlate directly to the cost per unit of the aircraft, but to the cost related to a reference point, that is, the water. It is also correct if the cost of the water is minimal, then the index value of its effectiveness will obviously be higher. If we ignore the cost of water and its index value is 1, the absolute and standard index values of the other extinguishers will be identical.

6.3. Comparative index

Following the above idea, the relative difference between the effectiveness of the delivery of the two extinguishers can be calculated with relation. This is the comparative index (W), which is the quotient of the standard index values of the two different extinguishers.

$$W = \frac{U_B}{U_A} \quad (24)$$

The result shows the difference between the effectiveness of the delivery of the two extinguishers. The farther its value is from 1, the bigger the difference is between the effectiveness. If the result is 1, there is no difference between the effectiveness of the delivery of the two extinguishers. It does not affect our calculations which data we use as the divisor or the dividend. Naturally, we get a higher quotient by dividing the higher value, so that extinguisher is more effective professionally. The relationship between the indexes of the delivery is depicted in Figure 2.

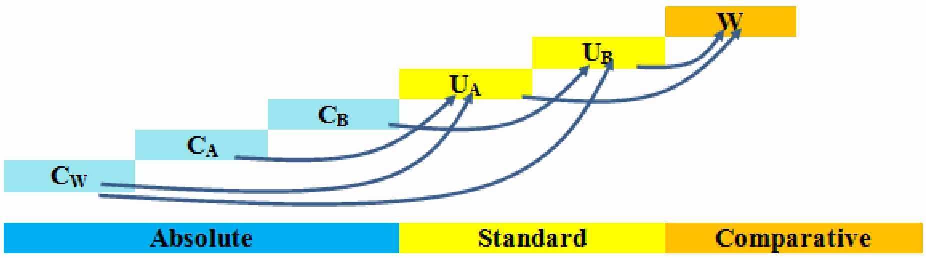

Figure 2 – Logic of the indexes of the professional effectiveness of the delivery

7. Summarizing

The creation of indexes and the calculations can be looked upon as a kind of mathematical game. It can be clearly seen how one consequence generates another one and also that, by keeping the basis of correlation, the new relations do not necessarily yield new results but rather a new approach to the results. The relationship between the indexes are summarised in Figure 6.

Despite the above, the creation of the indexes was not for their own sake. The paper has drawn attention to the fact that the extinguisher ability of extinguishers and the cost of their delivery can be examined together and that the separate analyses of their effectiveness do not necessarily lead to the correct conclusions. According to author's approach, it is possible - however difficult it is - to analyse and evaluate the effectiveness of aerial firefighting beyond the producers, distributors of the extinguishers and the marketing tricks of service providers of aerial firefighting even if the paper does not discuss each and every factor in detail.

The reasoning in the paper obviously changes with the modification of the influencing factors. We might assign different delivery means to the various extinguishers or even increase the number of extinguishers to be compared. We can get the results by expanding the formulas above or by interpolating the already existing results.

REFERENCES

American Society for Testing and Materials. Standard Test Method for Determining Material Ignition and Flame Spread properties; E1321-1997(02).

Batista, A.C.: Combustion characteristics tests of Magnolia grandiflora and Michelia champaca for potential use in fuelbreaks in south region of Brazil, Wildfire 2011 Conference, Sun City, South Africa, 2011

Fiorucci, P. a): PROPAGATOR: A Rapid and Effective Tool for Active Fire Risk Assessment, Wildfire 2011 Conference, Sun City, South Africa, 2011

Fiorucci, P. b): RISICO: A Decision Support System (DSS) for Dynamic Wildfire Risk Evaluation in Italy, Wildfire 2011 Conference, Sun City, South Africa, 2011

Morris C.J.: A simulation study of fuel treatment effects in dry forests of the western United States: testing the principles of a fire-safe forest, Wildfire 2011 Conference, Sun City, South Africa, 2011

Restas, A.: Az erdotuzoltas hatekonysaganak kozgazdasagi megkozelitese (Economical approach of the effectiveness of suppressing forest fire) Vedelem, 18:(5) pp. 47-50. (2011) ISSN 1218-2958

Underwriters Laboratories Inc. Project Reports to USDA Forest Service; 98NK32277, 99NK35219, 01NK12843, 03NK13445, 04NK16188, and 06CA42655.

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