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Theoretical solution for a logistic problem: how to raise the effectiveness of aerial water transport

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Abstract
Introduction: As well-known, aerial firefighting is an effective solution suppressing forest fire, however there is no doubt, this tool in many cases can be the only one effective solution, even if it is very expensive. Following the above idea, any new method that is able to reduce the cost of aerial means supporting forest fire management, is worth examining as a new aerial solution. Methods: This article used practical experiments of the aerial firefighting, created a graphics model to understand the logistic problem, made assumptions to concentrate on the key problems and with mathematical backgrounds some logistic functions meaning distance and capacity axes. Results and discussion: The effectiveness of air tankers depends on the distance between the fire zone and water resource. The shorter the distance is between them, the higher the effectiveness is using aerials. This relation can be shown even at a function; however the change is not linear. The rate of the curve depends on the distance, larger distance means smaller change and vice versa, shorter distance means bigger scale of change. This result gives the tipping point where the higher costs of suggested solution – aerial water supply system - will be balanced by the higher amount of bombed water.

***Keywords**: aerial firefighting, water transport, logistic problem, raising effectiveness*

1. Introduction

Each year thousands of hectares of forests burn causing a lot of damages in life, property and environment. As well-known forest fires cause also the 20% of the CO_2 emission generating greenhouse effects (Spessa, A. at al., 2013). Since the resources of managing forest fires are always limited, any new method, equipment or idea which can help managers is valuable to examine as a new solution.
As well-known, aerial firefighting is an effective solution suppressing forest fire, however there is no doubt, this tool can be the only one solution in many cases, even if it is very expensive (Ganewatta, G. and Handwer, J., 2009). Following the above idea, any new method or equipment, that is able to reduce the cost of aerial means supporting forest fire management, is valuable to examine as a new aerial solution. Higher effectiveness of aerial firefighting means that management can save more life, property and environment or can reduce the cost of intervention.

2. Problems and theoretical solution

Since the practice using aerial means for bombing water is accepted by the experts as a very effective tool fighting against forest fires, - but its high cost is commonly known also, - the question arises: how could the costs of this application be reduced or how could the effectiveness of this method be raised? Without deeper analysis, it is accepted, the effectiveness of the aerial firefighting strongly depends on the distance between the fire front and water resources. If the distance between them is relatively short, air tankers can take more cycles, it means high effectiveness; however long distance means obviously fewer cycles and lower effectiveness.
Since the distance between the natural water resources and fire front is independent from each other, forest services in many cases create fix, semi-fix or mobile water supply in the most threatened zones in the forest, for example for supporting helicopter attack. This water supply require resources, like

money, time to installation, humans to control, energy for upload, etc. however more and more installation means that, from the point of forest service view these tools are useful and its application is effective.
If fire occurs in the forest where these water supplies had been installed it means that this solution is or can be effective. If fire doesn't occur during the fire season in the forest where water supply had been installed before, all resources that forest service invested in these systems mean wasted money. The experience shows that, even if it has risks in necessity, a lot of efforts are made to install more and more water supply systems.

Figure 1. Mobile water supply system for supporting helicopter attack

The question is, if mobile water supply system is accepted as an effective tool for supporting the (aerial) fight against forest fire, – but it is obviously impossible to install and manage theme in each forest, even if it would be required by experts, – instead of these system an aerial version, like a huge air tanker as an logistic support can be used or not.
Scenario is as follows (Figure 3): a huge capacity air tanker carries the water between the water resource (airport/airfield) and fire zone. At the fire zone, this aircraft flies circles as an aerial water supply system and upload the water to the other, limited capacity air tanker(s). Smaller aircrafts are more mobile, they can bomb water in the most appropriate places, with more precision. In many cases, fire managers require just some water but in the right place to suppress fire, and huge air tankers carry many times more water than it is required for a precisions attack. The water bombed or used ineffectively means that, all the costs invested into carrying it from water resources (airport/field) to fire zone is lost money.

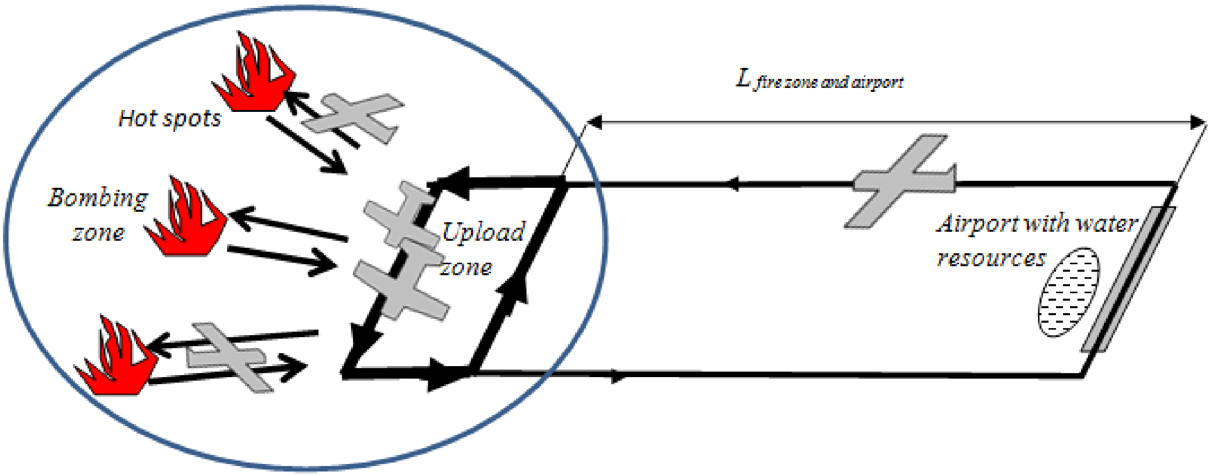

Figure 2. The structure of Aerial Water Supply System (AW2S)

The above scenario seems to be theoretical but not impossible. Many times, the aerial fuel tank is a normal procedure during military operations; therefore, it can be possible to solve the problem of aerial water upload. The question is less technical than economical: the scenario above can be economical effective or not; if the answer is yes, what conditions satisfy the minimum criteria of the required effectiveness?

This study focuses on the possibility of creating a new solution. Because of the limited time, resources and the frame of the study, author determined some assumptions. They make the theory easier to understand and find the essence of the advantages. Assumptions help readers not to get lost in the details but understand the essence.

Even if assumptions make this study simple, it is not allowed to generate false results at the end; counted assumptions are as follows:

- The scale of forest fire is large, aerial firefighting is required;
- Fire intensity is constant, forest area is homogenous, area is flat, there is no wind;
- Extinguishing material is water, aerial firefighting (bombing water) is effective;
- Study focuses on aerials' effectiveness from the logistics point of view but not from firefighting tactics;
- Study uses 2D logistic model;
- There is no problem with water upload from large tanker to small tanker(s).

3. Features of aerial activity

The effectiveness of air tankers depends on the distance between the fire zone and water resource. The shorter the distance is between them, the higher the effectiveness is using aerials. This relation can be shown even at a function; however the change is not linear. The rate of the curve depends on the distance, larger distance means smaller change and vice versa, shorter distance means bigger scale of change. This curve shows an exponentially decreasing function, where the index depends on the type of aerial tanks. Naturally, the curve never passes the axis; the close has an objective limit.

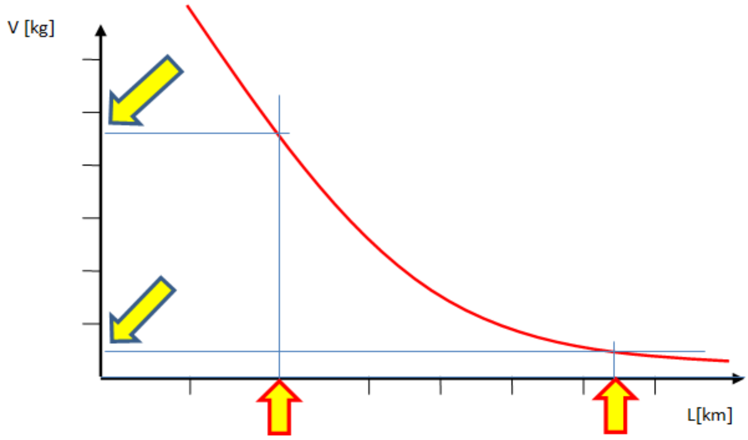

Figure 3- Effectiveness (bombed water) of aerial firefighting depending on the distance between the fire front and the water resource

Again, the shorter the distance is between the fire front and water resource, the more water is carried (bombed) water to fire front, in other words, higher the effectiveness of the aerial firefighting.

4. Essence of the aerial fire fighting's effectiveness

Experts rarely or never talk about the costs of disaster management. If human life, property or environment is suddenly threatened or hit by a disaster, like large scale forest fires, money doesn't count for politicians, even if the prevention or the higher readiness for response would cost much less. Ethically, human life is invaluable, thus in case of disaster speaking about the money or costs of the intervention is impoliteness.

Despite the above, it is easy to accept that, the essence of the effectiveness depends on the cost of intervention. Based on the given assumptions, the effectiveness takes into account with the amount of water - dropped to fire front, - carried by tankers, and the costs of operation hours paid for tankers' service. The rate of theme gives the costs of dropped extinguish (water) item (1 kg) at fire front (1).

$$\frac{\sum costs\ of\ aerials_{\$}}{\sum carried\ water_{kg}} = x\ \frac{\$}{kg} \qquad (1)$$

Basically, higher effectiveness means that we should carry more water with the same costs, or reduce the costs of the carried amount of water. This study approaches the above question with a special solution. This study examines the opportunity how the effectiveness changes if a large tanker as an aerial water supply is used. For this analysis, it considers two simple cases; they can be developed further based on the results this study determines, or giving up step by step the given assumptions.

In the first case, - let's say case of "A", - all water is carried to the fire front and dropped as usual by 1 small air tanker (2); its feature means:

$$A) \quad 1\ small\ air\ tanker\ (A) \rightarrow \sum water_A \rightarrow \sum costs_A \qquad (2)$$

In the other case, - let's say case of "B", - the water to fire zone is carried by a big air tanker (B) and there it is uploaded by airborne to the smaller air tanker (A). During this process the big tanker serves as a water supply system for the small tanker (A), meaning also that, small tanker can take shorter circles from water resource than without big tanker and resulting also higher amount of water, bombed to fire front (3); its feature means:

$$B)\quad 1\ small\ tanker\ (A) + 1\ big\ tanker\ (B) \rightarrow \sum water_B \rightarrow \sum costs_B \qquad (3)$$

In case of “B”, there is the same small tanker, as in case of “A”, and also a big tanker as an aerial water supply system, meaning that, the total costs in case of “B” are naturally higher than in case of “A” (4):

$$\sum costs_A < \sum costs_B \qquad (4)$$

The effectiveness can be expressed not just by the amount of water carried to the fire front, but also by the expenses, the water carried costs. If the costs or the amount of bombed water is equal, the effectiveness can be determined by ranking the other parameter. Since the costs in case of “B” are logically always higher than in case of “A”, it is easy to sense that, this study focuses on the *tipping point*, where the higher costs is balanced by the higher amount of water bombed (carried).
Tipping point means that, - with the assumptions given above, - the costs of 1 kg bombed water are equal in both cases; in other words, in both cases the economical effectiveness is the same or equal. In this case, the rate of costs (5) is the same or equal to the rate of water carried (6).

$$R_{costs} = \frac{\sum costs_A}{\sum costs_B} \quad (5)$$

$$R_{water} = \frac{\sum water_A}{\sum water_B} \quad (6)$$

$$\frac{\sum costs_A}{\sum costs_B} = \frac{\sum water_A}{\sum water_B} \quad (7)$$

$$R_{costs} = R_{water} \quad (8)$$

Moreover, the same effectiveness means that, the rate of the costs and the water bombed is equal in both cases (9) (10) (11).

$$R_A = \frac{\sum costs_A}{\sum water_A} \qquad (9)$$

$$R_B = \frac{\sum costs_B}{\sum water_B} \qquad (10)$$

$$R_A = R_B \quad (11)$$

Since the expenditures of the planes’ operation and also the water carried in case of “A” are known, the tipping point ($\Sigma water_B$) can be determined by ordering the above equals (12):

$$\sum water_B = \frac{\sum water_A \sum costs_B}{\sum costs_A} \qquad (12)$$

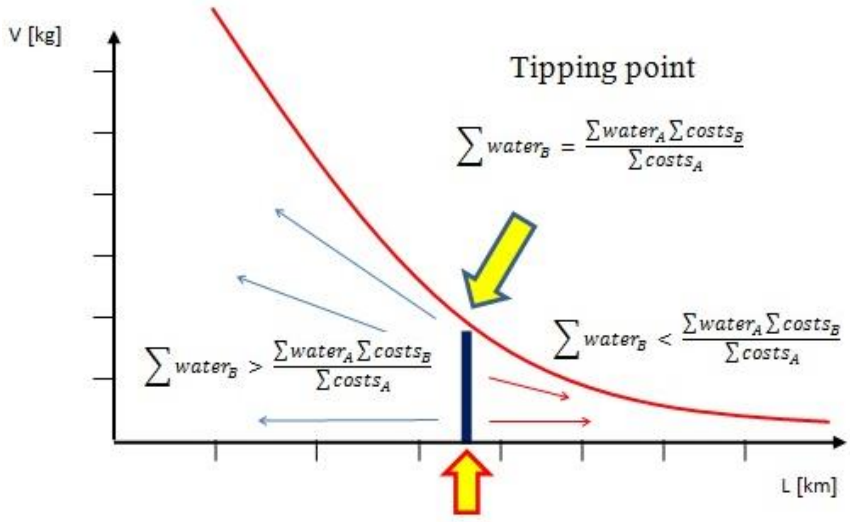

Figure 4. The structure of tipping point

This result gives the tipping point; in any case where the amount of water carried in case of “B” is bigger, the effectiveness is sure. The larger the difference is between the parts of the equal, the higher the effectiveness in the case of “B”. Since the costs of case “B” is logically always higher than the costs of case “A”, for the equal effectiveness the higher costs of case “B” must be balanced by the higher amount of bombed water.

5. **Required data for finding the tipping point**

Following the above, to determine the tipping point the distance between the water resource (airport) and the fire front, the costs of operation hour of used planes and the characteristic of the aircraft’s effectiveness function are required to know; based on these data a rate is resulted. Required data for determining the tipping point:

- Characteristic of the aircraft’s effectiveness function,
- Operation costs of air tankers (AW2S),
- Distance between the water resource (airport) and the fire front.

From the point of economical view there is no difference between the case of “A” and “B”; higher costs are balanced by more water. This equality doesn’t count with the fact that, in the case of “B” the carried (bombed) water is obviously more than in the case of “A”; this fact is an extra advantage (effectiveness) of the case of “B”. Considering this advantage or the evaluation of its real value requires another study but the recognition of this fact shows squarely the viability of the aerial water supply system.

6. **Finding examples for the test**

Look at an example; if the operation costs of a large tanker is 3 times higher than the small tanker’s one, the total costs of the case of “B” are 4 times more than case of “A”. Rate of costs is 4, meaning that the required water supply for equal effectiveness by the new system (AW2S) for bombing at the same situation is 4 times more too. Based on table 1, costs are not too far from each other; therefore, there is a chance for finding applicable solution for the aerial water supply system (AW2S).

Table 1—Examples for flying costs[1]

	Type	Costs of flying hour [$€h^{-1}$]	Costs of flying minute [$€min^{-1}$]	Source
1.	S-2T	1800	30	Conf. pres.
2.	G-IIIAT	3240	54	Conf. pres.
3-	C-130	6000	100	Internet
4.	C-27 Spartan	7000	117	Internet
5.	CL-415	8640	144	Conf. pres.
6.	BE-200	11500	192	Company
7.	ShinMeiwa	16200	270	Company
8.	B-747 Super tanker	5500[2]	92	Company

To test the new system, author suggests the S-2T as the small aircraft and an often used military plane, example C-130, C-27 or An-26 as the cheapest version of "large" capacity air tanker. Each of them is robust, has relatively low operation costs and easy to test. C-130 can carry much more payload (water) than the difference between the flying costs of S-2T and C-130.

7. Some remarks regarding the results

There are three remarks, first is: naturally other platforms generate other results of the above rate. Even if it seems to be easy to choose or find a version of AW2S which is effective, but the effectiveness is not for itself; it must satisfy the criteria at as low costs level as possible. Results without the latest criteria can satisfy the requirements of the effectiveness of the aerial water supply system but they might not meet the requirements of the effectiveness of aerial firefighting.
Second remark focuses on the tipping point. From the point of economical view they are totally the same, the higher amount of water is carried by a complex system (case of "B" – AW2S) or by the rate times more single solution (in the above example: 4 x case of "A"). Naturally the above statement is valid only at the tipping point.
The difference between the rate of the tipping point and the rate of the payload (water) capacity (6) is very important. The higher the difference is between them, the higher the effectiveness of the aerial water supply system; it results also in a higher effectiveness of aerial firefighting.

8. Analysis of the function's characteristic

Depending on the characteristic of the air tankers' function, the distance between the fire front and water resource (airport) and the rate of costs "A" and "B" gives the orientation of the tipping point on the curve. Even if the above seems difficult, it is not so. If the aerial water supply system can serve more water than the rate is, the system is effective. Not just the payload capacity but also the operation costs of aerial tankers are known by the users, moreover, the distance between the fire front and the water resource (airport) is also known immediately after the fire alarm; thus, using the given equals above the fire management can calculate the tipping point relatively easily helping the quick and right *yes* or *no* decision.

[1] Presentations and expert estimation; Theo, M.T., Aerial Fire Fighting Conference, Rome, Italy, 2009
[2] Special costs, given by the Evergreen service; it seems, must be critics.

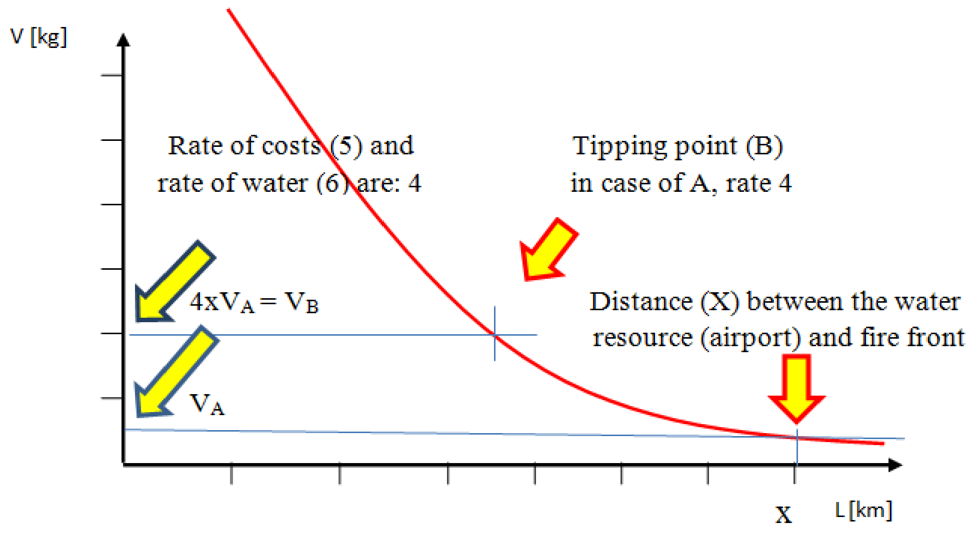

Figure 4. Analysis of the air tanker's effectiveness function

Moreover, to help the effective application even special software can be created for example by GIS based program. On the known parameters the program can classify different zones at the responsible area and indicate it on the intervention map, where the classification can quantify from the point of economical view the effectiveness of the AW2S application.

Based on the characteristic of the function, it is easy to sense that in case of large distance between water resource and fire front it is much easier to reach the tipping point, it is realized at lower level and vice versa, if the distance is shorter, to reach it is more complicated (higher level). Following this process there is a point where the case of "B" practically can't be better solution than the case of "A" because the system objectively can't carry as much water as the balance (tipping point) requires. It is necessary to count with the fact that, the rate of function is not linear, exponential curve has a negative index.

Since the idea generated in this study focuses on the problem of long distance between water resource and fire front, the above extremity is not relevant.

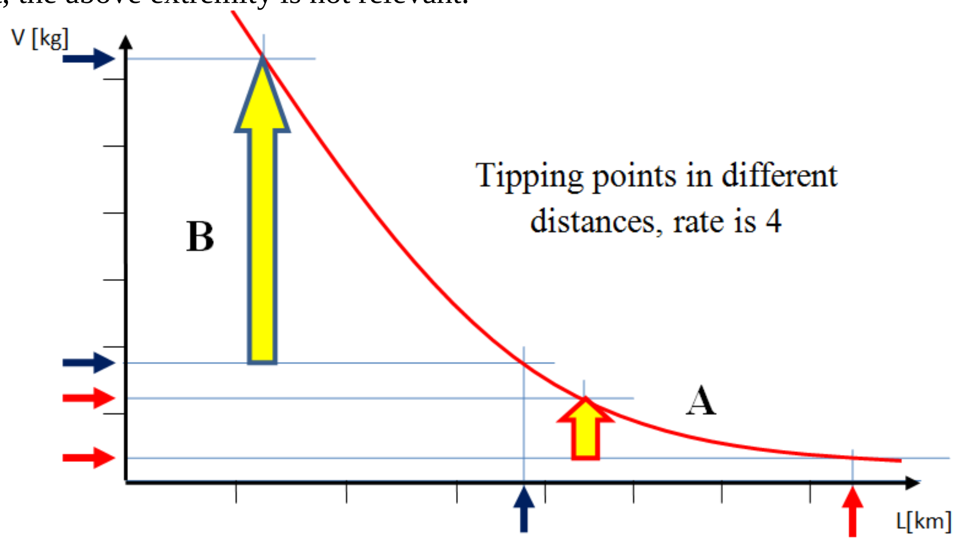

Figure 5. The difference of the requirements depending on the distance between the water resource and the fire front

9. Short summarizing

Based on this study, the aerial water supply system (AW2S) is a good idea and can be an effective solution. Even if the study made assumptions, the end results of the evaluation shows that the AW2S is a viable method not just from the point of professional but also economical effectiveness view. The realization is rather a technical than economical question. There is no doubt, in certain conditions AW2S can be a better and more effective solution than the aerial firefighting pattern used today.

10. References

Ganewatta, G. and Handmer, J.: The Cost Effectiveness of Aerial Fire-fighting in Australia; Centre for Risk and Community Safety, RMIT University, Bushfire CRC, ISBN: 978-0-9804594-3-2, April 2009

Spessa, Allan; van der Werf, Guido; Thonicke, Kirsten; Gomez Dans, Jose; Lehsten, Veiko; Fisher, Rose and Forrest, Matthew . Modeling vegetation fires and fire emissions. In: Goldammer, Johann Georg ed. Vegetation Fires and Global Change – Challenges for Concerted International Action. A White Paper directed to the United Nations and International Organizations. Kessel, 2013. pp. 181–207.

Theo, M.T.: Initial Attack Air Tanker - Marsh S-2AT Turbo Tracker; Presentation, Aerial Fire Fighting Conference, Rome, Italy, 2009