# Economic aspects of disaster management focusing on firefighting equipment

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**Abstract**. To maintain the fire department, it needs significant state budget expenditure but against the above it is still enjoying a high degree of confidence of the majority of the population. It is therefore particularly important to pursue an effective professional firefighting work and cost effective management. Authors reviewed the little professional literature available of this topic, used theoretical approaches, logic conclusions and - naturally - practical experiences of firefighting with its caused effects. Generally, efficiency is the relationship between achieved results during a certain activity, as well as the resources used to achieve them. How do we understand it in the firefighter actions? For technical (firefighting) efficiency clear values can be calculated (e.g. by duration of firefighting, used power and devices). The analysis of the economic efficiency is a more difficult task. On the resources side is required more precise definition of the total cost of used powers and tools; however the achieved results (saved values), are often difficult to be calculated (e.g. vegetation fires) and in some cases the result of the action - human life, monuments, natural habitats - cannot be expressed by monetary terms. The determination of measuring economic efficiency and ranking firefighting techniques may help to make procurement and cost-effective operation decisions.
**Key Words**: disaster management of economic view, fire protection, firefighting equipment, efficiency, cost-effective operation.

**Introduction**. The effectiveness of fire-fighting equipment is interpreted in two perspectives. One of them is the technical or professional efficiency, which means to save lives, early elimination of fire and minimization of damages with the use of available forces (Restas 2015). The technical or professional efficiency of the firefighter actions affected three main aspects, these are the duration of the arrival, the duration of the preparation of the firefighter action and the fast realized high extinguishing effect. These are affected by the applied fire-fighting equipment and tactics, the improvement of efficiency can be achieved through mainly technical improvements.

This study focuses mainly on the effectiveness of firefighting actions, however we can find other approaches; we can find studies focusing on the effectiveness of the extinguishing materials (Restas 2014a, b), the rules of fire prevention in buildings (Balázs & Lublóy 2010a) (Kerekes 2014) or structures of buildings (Balázs & Lublóy 2010b), the forest fire detection systems (Restas 2014a, b) or the aerial firefighting methods (Restas 2014b, c). Even if each of them use different methods the results point out the importance of measuring the effectiveness of the “fire” topics.

The economic efficiency of firefighter actions is affected by the cost of the action, the saved value and the secondary damages caused by the firefighter actions. There are many components of the intervention costs, some of them can be reduced with the technical development of fire-fighting equipment. On the other hand, some of the cost elements originated from the organization's structure and the speciality of the 24 hour service.

They are independent of the technology level, but represent a significant part of the costs. The analysis of the last two points, the saved value and the secondary damage can be only uniquely interpreted. Generally, in these cases, the correlations of the technical level of the fire fighter equipment and the impact on efficiency should only be analysed.

## Elements of the technical efficiency

***The duration of the arrival**.* The crew of a professional fire department shall leave their base (normally) within 120 seconds after the alarm signal (Legislation 1). The duration of the arrival ideally depends on the distance and the speed. Recently, the distance for the furthest village is about 20-25 km. Most of the fire trucks have an operating mass around 15 tons, including full water tank. Due to their high center of gravity - for security reasons - the maximum speed is limited to about 70-90 km/h. It should not be forget the other disturbing factors, like traffic jams, for example. If the required amount of delivered water can be reduced, and the crew and the equipment can be placed in a lighter vehicle, we obtained a much faster and more agile fire fighting device. So, the quick arrival can be ensured by light vehicles. To make the extinguishing performance of the vehicle not reduced, required more effective water consumption (e.g. use of high pressure equipment).

***The duration of the preparation of the firefighter action**.* Before the fire fighting action, the crew assemble a multi-jet firefighting line using B-hoses, divider, C-hoses and nozzles and make a water supply from the fire hydrant, using B-hoses. This takes serious minutes. In case of smaller fires often remain the assembly, will only use the 60-meter long, pre-assembled quick-use hose, with which the fire fighting action can start immediately. In this case, the hose cannot be extended, but the 60-meter length is sufficient in many cases. Firefighter action can be started quickly if the compilation of the fire fighter equipment requires little on-site installation (e.g. use of pre-assembled quick-use hose and/or high pressure equipment).

***Fast realized high extinguishing effect***. From a fire engine (crew: 6 persons) is no more than two jets which can be assembled, because there are only two pre-assembled quick-use jets. The mass of a conventional C-hose, including water is more than 2 kg per meter, so the full mass of the applied hose is between 80-120 kg, depending on its length. To move this, two persons are necessary for each jet, so the treatment of maximum two conventional C-jets is possible (the crew leader and the driver do not use any hose). Only one person is enough for the treatment of a much thinner quick-use hose or an even thinner high-pressure hose, so each firefighter can use his own jet (for security reasons, they work in pairs). An effective firefighter action can be achieved by using much more extinguishing jet.

## Elements of the economic efficiency

***Cost of the firefighter action**.* During the extinguishing, the following costs arise: the cost of manpower; operating costs (the fule cost included here); amortization; the cost of the extinguishing material (Everett et al 2014). The amortization is significantly different from economic and technical point of view, the most effective tool being the one which is older than the amortization period.

In the following we make a comparison of four typical fire engine types from different weight classes:

- heavy-weight class (Mercedes 1234 Rosenbauer TLF 4000 AT) (Figure 1): crew- 6 persons; length - 6.820 mm, width - 2.460 mm; height - 3.280 mm; GVW - 15.550 kg; pump type - Rosenbauer NH 30; pressure range - normal (10 bar) + high (40 bar); quick-use jets - 2 x 60 m (200 litre/min); water tank - 4000 litres;
- medium-weight class (Mercedes 1124 Rosenbauer TLF 2000 AT) (Figure 2): crew - 4 persons; length - 6.840 mm; width - 2.340 mm; height - 3.120 mm; GVW - 12.580 kg; pump type - Rosenbauer NH 30; pressure range - normal (10 bar) + high (40 bar); quick-use jets - 2 x 60 m (200 litre/min); water tank - 2000 litres;
- light-weight class (Mercedes 814 D Rosenbauer TLF 1000 AT) (Figure 3): crew - 4 persons; length - 5.450 mm; width - 2.240 mm; height - 3.000 mm; GVW - 7.500 kg; pump type - Rosenbauer NH 20; pressure range - normal (10 bar) + high (40 bar); quick-use jets -1x 60 m (200 litre/min); water tank: 2000 litres;

- under 3,5 tons (Nissan Navarra Highway Rescue Heros) (Figure 4): crew - 1 person; length - 5.450 mm; width - 2.240 mm; height - 3.000 mm; GVW - 7.500 kg; pump type - Rosenbauer NH 20; pressure range - normal (10 bar) + high (40 bar); quick-use jets - 1x 60 m (200 litre/min); water tank - 1000 litres.


Figure 1. Mercedes 1234 Rosenbauer TLF 4000.


Figure 2. Mercedes 1124 Rosenbauer TLF 2000.


Figure 3. Mercedes 814 D Rosenbauer TLF 1000.


Figure 4. Nissan Navarra Highway Rescue.

***Fuel consumption***. Several methods exist for calculating the cost of the fire fighter actions; the major elements of the calculation are the cost of fuel and the cost of extinguishing media, which are variable costs, and easy to calculate. In the following we put together the fuel consumption data of the four typical fire engine type. Eliminating the technical conditions and the speciality of the different vehicle types in a weight class, the theoretical fuel costs are calculated by law, with the following formulas (Legislation 2), available for diesel-powered trucks manufactured since 2002:

| Gross vehicle weight (kg) | Base norm (liter/100 km) „An” |
|---|---|
| 2 500-3 500 kg | $An = 5 + 0.0005 \times (Gm + Gs) + 0.047 \times N$ |
| 3 501-8 000 kg | $An = 8.5 + 0.0005 \times (Gm + Gs) + 0.043 \times N$ |
| 8 001-16 000 kg | $An = 9.5 + 0.00047 \times (Gm + Gs) + 0.041 \times N$ |
| over 16 001 kg | $An = 13 + 0.00047 \times (Gm + Gs) + 0.040 \times N$ |

where:
a) type of vehicle,
b) weight [Gs (kg)],
c) maximum authorized mass [Gm, (kg)],
d) seating capacity (persons)
e) motor power [N (kW)]
f) vehicle design,
g) type of fuel.

As a result, by the calculation of consumption the following values were found as presented in Table 1.

Table 1

The tested fire engines theoretical fuel consumption data (Source: authors)

| *Type of vehicle* | *Fuel consumption (litre/100 km)* |
|---|---|
| Nissan Navarra Heros Highway Rescue | 18.29 |
| Mercedes 814 D Rosenbauer TLF 1000 AT | 25.74 |
| Mercedes 1124 Rosenbauer TLF 2000 AT | 35.96 |
| Mercedes 1234 Rosenbauer TLF 4000 AT | 47.50 |

Of course, this is not a reasonable comparison, because these vehicles have not the same fire-fighting performance. In order to a better comparison, we defined a unit, the so called specific extinguishing performance (SEP), which is equal to the extinguish performance of a conventional 10 bar pressure jet (250 L/min).

The drop sizes belong to different pressures sizes will approach using the Table 2. We consider the extinguishing performance is directly proportional to the size of the liquid surface.

Table 2

Drop size, volume of drops and gross liquid surface (Bot 2014)

| *Drop size (mm)* | *Number of drops (pc.)* | *Gross liquide surface ($m^2$)* |
|---|---|---|
| 10 | 1 900 | 0.6 |
| 1 | 1 900 000 | 6 |
| 0.1 | 1 900 000 000 | 60 |
| 0.01 | 1 900 000 000 000 | 600 |

According to the above, the specific extinguishing performances (SEP) are as follow in Table 3. In case of a four person crew, we note that two quick-use jets can operate simultaneously. It seems that the higher pressure equipment (also the quick-use jets) has larger theoretical extinguishing effect.

Table 3

Specific extinguishing performances of the tested vehicles (Source: author)

| *Type of vehicle* | *Jet* | *Litre/min.* | *Bar* | *Mm* | *$m^2$* | *SEP* |
|---|---|---|---|---|---|---|
| Nissan Navarra Heros Highway Rescue (150 bar) | 1 | 20 | 160 | 0.08 | 160.00 | 2.16 |
| Mercedes 814 D Rosenbauer TLF 1000 AT (40 bar) | 1 | 115 | 40 | 0.6 | 20.00 | 1.52 |
| Mercedes 814 D Rosenbauer TLF 1000 AT (10 bar) | 1 | 250 | 10 | 1 | 6.00 | 1.00 |
| Mercedes 1124 Rosenbauer TLF 2000 AT (40 bar) | 2 | 115 | 40 | 0.6 | 20.00 | 3.04 |
| Mercedes 1124 Rosenbauer TLF 2000 AT (10 bar) | 1 | 250 | 10 | 1 | 6.00 | 1.00 |
| Mercedes 1234 Rosenbauer TLF 4000 AT (40 bar) | 2 | 115 | 40 | 0.6 | 20.00 | 3.04 |
| Mercedes 1234 Rosenbauer TLF 4000 AT (10 bar) | 2 | 250 | 10 | 1 | 6.00 | 2.00 |

The fuel consumption divided by the specific extinguishing performances shows us the fuel consumption per extinguishing unit (Table 4).

Table 4

Fuel consumption data of the tested fire engines per extinguishing unit (Source: author)

| *No.* | *Type of vehicle* | *Litre/100 km (SEP)* |
|---|---|---|
| 1 | Nissan Navarra Heros Highway Rescue (150 bar) | 8.47 |
| 2 | Mercedes 1124 Rosenbauer TLF 2000 AT (40 bar) | 11.84 |
| 3 | Mercedes 1234 Rosenbauer TLF 4000 AT (40 bar) | 15.64 |
| 4 | Mercedes 814 D Rosenbauer TLF 1000 AT (40 bar) | 16.96 |
| 5 | Mercedes 1234 Rosenbauer TLF 4000 AT (10 bar) | 23.75 |
| 6 | Mercedes 814 D Rosenbauer TLF 1000 AT (10 bar) | 25.74 |
| 7 | Mercedes 1124 Rosenbauer TLF 2000 AT (10 bar) | 35.96 |

***Extinguishing media consumption***. There are cases when the extinguishing with water has low efficiency or it is even ineffective. Such cases are the extinguishing of porous solids, flammable liquids, or cooling of hot metal surfaces, which are required extinguishing foam. The price of the foaming substance represents a significant cost ratio. The mixing ratio is usually 1 to 3%. Because of the different pricing method of the different sources of supply, we examined the foaming substance consumption, taking into account a 15 minute net operation period and a 1% mixing ratio. The results are valid per extinguishing unit (Table 5).

Table 5
Foaming substance consumption data of the tested fire engines per extinguishing unit (Source: author)

| *No.* | *Type of vehicle* | *Litre/15 min. (SEP)* |
|---|---|---|
| 1 | Nissan Navarra Heros Highway Rescue (150 bar) | 1.39 |
| 2 | Mercedes 814 D Rosenbauer TLF 1000 AT (40 bar) | 11.36 |
| 3 | Mercedes 1124 Rosenbauer TLF 2000 AT (40 bar) | 11.36 |
| 4 | Mercedes 1234 Rosenbauer TLF 4000 AT (40 bar) | 11.36 |
| 5 | Mercedes 814 D Rosenbauer TLF 1000 AT (10 bar) | 37.50 |
| 6 | Mercedes 1124 Rosenbauer TLF 2000 AT (10 bar) | 37.50 |
| 7 | Mercedes 1234 Rosenbauer TLF 4000 AT (10 bar) | 37.50 |

***Personnel costs***. The standby (or availability) costs, have a value depending on many factors such as the experience and age of the crew, the utility costs, but mostly on the annual number of firefighter actions. For the simple comparison, we examined only the number of persons in a crew, without taking into account the different payments and the annual number of firefighter actions. The TLF 4000 AT has a crew of 6 persons, there is one person in the Nissan, and the others have a crew of 4 persons. The number of persons in a crew divided by the specific extinguishing performances shows us the theoretical necessary human force per extinguishing unit (Table 6).

Table 6
Theoretical human force per extinguishing unit of the tested vehicles (Source: author)

| *No.* | *Type of vehicle* | *Person/SEP* |
|---|---|---|
| 1 | Nissan Navarra Heros Highway Rescue (150 bar) | 0.46 |
| 2 | Mercedes 1124 Rosenbauer TLF 2000 AT (40 bar) | 1.32 |
| 3 | Mercedes 1234 Rosenbauer TLF 4000 AT (40 bar) | 1.98 |
| 4 | Mercedes 814 D Rosenbauer TLF 1000 AT (40 bar) | 2.64 |
| 5 | Mercedes 1234 Rosenbauer TLF 4000 AT (10 bar) | 3.00 |
| 6 | Mercedes 814 D Rosenbauer TLF 1000 AT (10 bar) | 4.00 |
| 7 | Mercedes 1124 Rosenbauer TLF 2000 AT (10 bar) | 4.00 |

***The saved value***. Usually, the saved value can only be estimated, because even by using a computer simulation it is difficult to determine the directions and the rate of the spread of fire. Among the many fire safety legislative requirements, an important one is to prevent the spread of fire (design of fire sectors, fire-proof structures, built-in extinguishing systems, etc.). But it is sure a fast firefighter action clearly increases the saved value. In case of a forest fire (Figure 5), the damage-time function gives an exponential curve (Restas 2012), however in normal case it shows ended form (Kuti 2009).

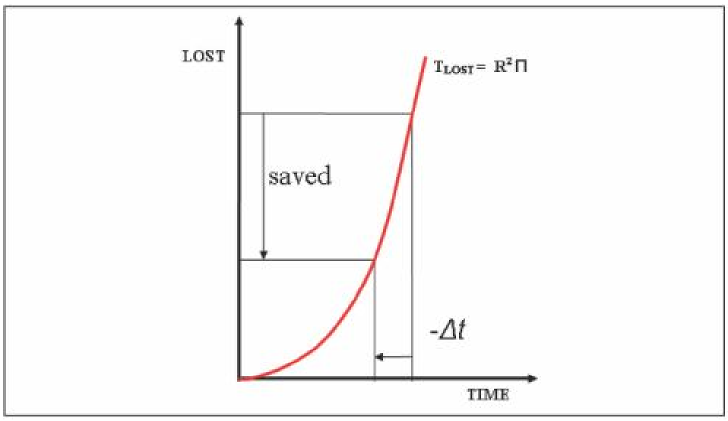


Figure 5. Damage-time function. Basic shape at uncontrolled forest fire (Restas 2012).

***The secondary damage***. A basic demand is that the goods saved from fire not to be destroyed due to the harmful effects of the water. The secondary damage are caused by the possible demolition during fire fighting, but mostly by the flooding of extinguishing water. Ideally, the water has completely evaporated during the firefighter action, using the heat of evaporation to cool the burn. The amount of water that is beneath the flames, on the floor flow, is not taking part in the extinguishing procedure, therefore, it is regarded as a wasteful excess. This amount of water is the major cause of the secondary damage, so it has to be definitely minimized. Efforts should be made for the highest possible level of vaporization; suitable for this purpose are the diffuse or aerosolized jets, or the high-pressure equipment. The secondary damage may also be difficult to calculate, but it is evident that the reduced use of extinguishing media (water) involves less damage.

**Discussion**. The comparison of the effectiveness of firefighting equipment was carried out on points, the points came from fuel costs, extinguishing media costs and personnel costs. All results relate to specific extinguishing performances which represents the technical side of the efficiency. The less point means lower cost and greater efficiency. The following ranking occurred (Figure 6):

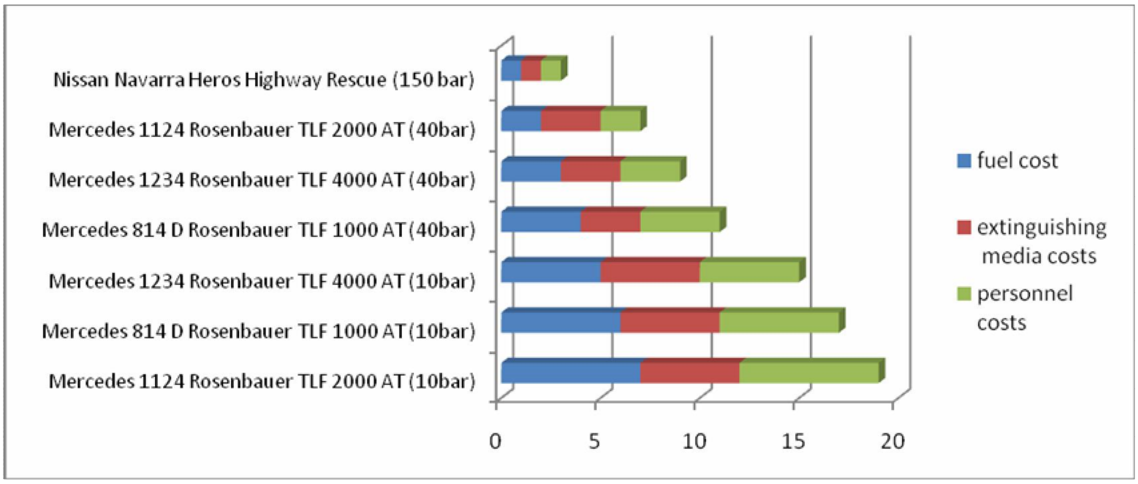


Figure 6. The ranking of the tested fire engines according to effectiveness (Source: author).

So, according to Figure 6, we can state the following:

1. Nissan Navarra Heros Highway Rescue (150 bar): the Navarra is fast, uses a few extinguishing media and category B driving license is needed. The disadvantage is the small water tank (100 litres). The high pressure pump is driven by its own gasoline motor, motor fuel uploading can be performed only when the engine is standing;
2. Mercedes 1124 Rosenbauer TLF 2000 AT (40 bar): with quick-use jet tested TLF 2000 AT fire engine has a prominent place due to the lower weight, lower personnel costs (only 4 person), but two 40 bar quick-use jets ensure an efficient extinguishing;
3. Mercedes 1234 Rosenbauer TLF 4000 AT (40 bar): with quick-use jet tested TLF 4000 AT fire engine has a prominent place as well, even though its costs far the highest in the comparison;
4. Mercedes 814 D Rosenbauer TLF 1000 AT (40 bar): despite the lower weight, lower fuel consumption, personnel costs are the same as the other engines and the only one quick-use jet provides only half of the extinguishing performance;
5. Mercedes 1234 Rosenbauer TLF 4000 AT (10 bar): at the end of the list, there is the TLF 4000 AT fire engine with a 10-bar technology, ahead of its lighter rivals, because only it has a 6 person crew, which is absolutely necessary for the using of the two conventional jets;
6. Mercedes 814 D Rosenbauer TLF 1000 AT (10 bar): the TLF 1000 AT fire engine with a 10-bar technology has overtaken the heavier, more fuel consumer, but only the same 4 person crew rival. The extinguishing performance in both cases is very limited;

7. Mercedes 1124 Rosenbauer TLF 2000 AT (10 bar): it is clear that the TLF 2000 AT fire engine with a 4 person crew and conventional, 10 bar technology can not be economical.

**Conclusions**. The examination of the technical (fire-fighting) efficiency revealed that the obvious way to increase the effectiveness is to increase the efficiency of the use of extinguishing media, to increase the number of the direct fire fighting persons and the use of more pre-assembled, quick-use fire-fighting equipment. Economic efficiency is closely related to the technical efficiency, especially the variable costs of the fire fighter action (fuel, extinguishing media, etc.). In this connection, it is worth to examine the application of more light weight class firefighter vehicles instead of a heavy- or medium-weight class firefighter vehicles. This will avoid using excessive force in case of smaller fires and improves mobility in case of other fire fighter actions.

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Received: 31 July 2017. Accepted: 13 September 2017. Published online: 30 September 2017.
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How to cite this article:
Halassy G., Restas A., 2017 Economic aspects of disaster management focusing on firefighting equipment. Ecoterra 14(3):44-52.