Cent. Eur. For. J. 68 (2022) 238–250 sciendo DOI: 10.2478/forj-2022-0009
CENTRAL EUROPEAN Forestry Journal
REVIEW PAPER
http://www.nlcsk.sk/fj/

Technological employment of fire-fighting adapter to increase the efficiency of extinguishing forest fires

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Abstract
The paper presents the results of the solution defining the possible application of the adapter as a fire-fighting mobile device with a base machine of a forest wheeled skidder (LKT) in the fire protection of forests in the Slovak Republic. Following the challenging accessibility to fire-fighting machinery during any intervention in forestry operation, the main aim was formulated. It will be about basic technical parameters of the DATEFF fire-fighting adapter, resulting from operational measures and following specification of its tactical deployment in extinguishing forest fires. This fact also follows from based on statistically processed data on fire in state forests of the Slovak Republic in the last ten years. The greatest damage occurs mainly the forests at a slope gradient of 16%. Designed fire adapter is structurally designed mainly to these terrains. Regarding its design and technical parameters, the proposed DATEFF adapter can be employed tactically as fire-fighting mobile device. In the case of an unavailable water source without access to the forest transport network, the adapter can be used as a part of long-distance water transport or as a mobile device for emergency import of material. Another option is to use it as a water tank in inaccessible terrain with the possibility of refilling using a Bambi bag and a helicopter. This fire-fighting adapter DATEFF is designed for forest wheel tractors that reach 40% slope availability, are able to work on the stand area, overcome obstacles and are available in sufficient quantities in all Slovak forest owners.

Key words: forest fires; distance; forest wheeled skidder; statistic; tactic; slope gradient

Editor: Jaroslav Holuša

1. Introduction

Regarding forest protection, forest fires are the most drastic form of forest destruction. They have an enormous impact on all forest ecosystems, in particular the plants and animals living in the area. From a technical point of view, a forest fire is a sudden, partly, or very uncontrolled incident. At the same time, it is an event limited in time and place with a negative impact on all social functions of a forest (productive or non-productive). This complex of physical and chemical effects is based on non-stationary processes (changing in place and time) like a burning, gas exchange and heat transfer (Hnilica et al. 2020).

The uncontrolled spread of forest vegetation, grassland and agricultural crop fires is a global phenomenon (Scott et al. 2014; Weise & Wright 2014), which may be linked to the foreseen climate and meteorological conditions. Oftentimes they result in large-scale incidents, which have substantial negative economic, social, and environmental consequences (Attiwill et al. 2013; Bowman et al. 2017; Tedim et al. 2018). Wildfires, also known as forest fires, bushfires, and unplanned fires, occur in landscapes across the globe (Krawchuk et al. 2009; Bowman et al. 2011). They represent a complex phenomenon consisting of many processes (for example the character of combustible material, combustion process, release, and transfer of energy) that occur in a large extent in space and time scales. These processes are crucial for alerting relevant persons and supporting their decision making, the wide scale of applications for management (control) of fires as well as creating measures to prevent large fires (Gill et al. 2013; Stephens et al. 2014). Such applications may be aimed at identifying fire hazards and issuing fire warnings (Brown & Davis 1973; Harris et al. 2017; Deeming et al. 1977), an assessment of the risk of fire occurrence in the natural environment (Ager et al. 2010; Majlingová 2015), modelling the behaviour of fire in various types of vegetation (for example grasslands, forests, bushes), planning of fire-fighting tactics and predicting the impact of fire from different perspectives (Johnson & Miyanishi 1995; Reinhardt et al. 2001).

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Ongoing climate change and its consequences are often discussed in professional circles as the main cause of future increased frequency of natural disasters, including fires in the natural environment. Climate change affects forest fires directly through weather conditions, which influence the onset and spreading of forest fire, and indirectly through its impact on vegetation and combustible material. It is assumed that the risk of forest fire occurrence in Europe will increase with the most extreme forest fires occurring more frequently, which destroy vast areas and have long-term consequences. Results of studies on forest fires, which occurred in the European continent in the last 30 years, show an increase in the duration of a fire season and it is assumed that a fire regime will change almost everywhere across Europe. While the total area in the South European countries destroyed by forest fire is increasing each and every year, northern areas like Scandinavia are afflicted by unprecedented forest fires (Moreno et al. 2014; Abatzoglou et al. 2019; Krikken et al. 2019; Kirchmeier-Young et al. 2019; Williams et al. 2019; Dupuy et al. 2020).

Due to global warming and increasing aridity, the risk of increased frequency and extent of wildfires is very high. Many regions of the world have experienced an increasing trend of excessive wildfires and an increasing occurrence of extremely severe fires (FAO Fire management 2006). The total area of forest fires in the EU over the last 20 years has been around 8.7 million hectares, with an annual average of around 415,000 hectares. The most extensive forest fires were recorded in 2000, 2003, 2005, 2007, 2012 and 2017. The forest fires in these years were above the annual average (San-Miguel-Ayanz et al. 2020). In 2017, wildfires burnt be around 1 million hectares of natural lands in the EU. The European Forest Fire Information System estimated the number of fire-related losses to be around 10 billion Euros [San-Miguel-Ayanz et al. 2018). Despite the prevention measures, in the Slovak forests there appeared 3081 forest fires in the period of 2007–2018 with direct material loss of 9.063.805 Euros, 24 injuries, and 4 fatalities (Fire and Rescue SR 2020). Despite the annual preventive measures taken in the field of forest fire protection, in 2019 there was a 30% increase in the number of forest fires compared to the previous year, and the year 2020, not statistically closed yet, brought a further increase in forest fires. At the same time, the damaged area increased by 170.7 hectares this year, compared to 2019. In 2020, there was also an increase in the destroyed forest area to 65 hectares, compared to 11.8 hectares in 2019, which represents an increase of more than 452% (Green report 2019; Green report 2020).

According to the statistics (Fire and Rescue SR 2014), there was no significant reduction in the risk of forest fires mostly due to these factors:

– increase of forest areas affected by the bark beetle's outbreak, which exceeds the impact of wind disaster in the year 2004,
– underestimation of factors observed in the period up to the year 2007,
– lack of financial resources for close monitoring (aerial, ground), aimed at early detection of forest fires at an early stage of their occurrence,
– failure in construction of sufficiently complex forest transport network in hazardous locations for various reasons,
– permanent lack of ground fire-fighting machinery for detection and destruction of forest fires in difficult mountainous terrain of Slovakia.

Based on the provided results, it can be concluded that mainly the last three factors have a major impact on the scale of forest fires, which depends on the late detection of a forest fire and the problem of terrain accessibility for any intervention of fire brigades (Hnilicová et al. 2016).

Following the previous results, mostly the challenging accessibility to fire-fighting machinery during any intervention in forestry operation, the main aim was formulated. The main aim of this study is to define basic technical parameters of the DATEFF fire-fighting adapter, resulting from operational measures and following specification of its tactical deployment in extinguishing forest fires.

2. Forest fires in Slovakia

Forest fires in Slovakia often occur in the areas inaccessible to fire-fighting machinery with insufficient or rather inadequate water supply for fire-fighting purposes. The facts provided above are based on statistically processed data on fire in state forests of the Slovak Republic in the last ten years. The data was distributed according to the terrain gradient. The gradient of up to 16% allows for a faster intervention even with the existing technology. These conditions enable a fast transportation of the extinguishing agent (water) to the place of intervention. Requirements for the accessibility of fire-fighting equipment increase with the terrain gradient rising over 16%, which stems from its technical design. This, in turn, leads to a slower distribution of water to the places requiring intervention (Fig. 1, 2 and Table 1).

According to these results, there can be concluded that the greatest damage is caused by fires in the forests of the Slovak Republic at a slope gradient of 16 % (Table 1).

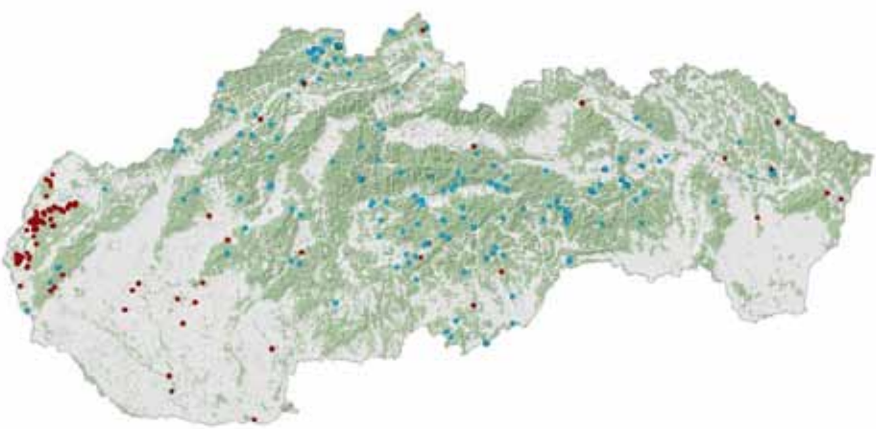

Fig. 1. Map of fires in state forests of the Slovak Republic in 2010–2020: red marks – forest fires in the terrain with a slope below 16%; blue marks – forest fires in the terrain with a slope over 16%. (© LESY Slovenskej republiky, state enterprise, Banská Bystrica, 2021).

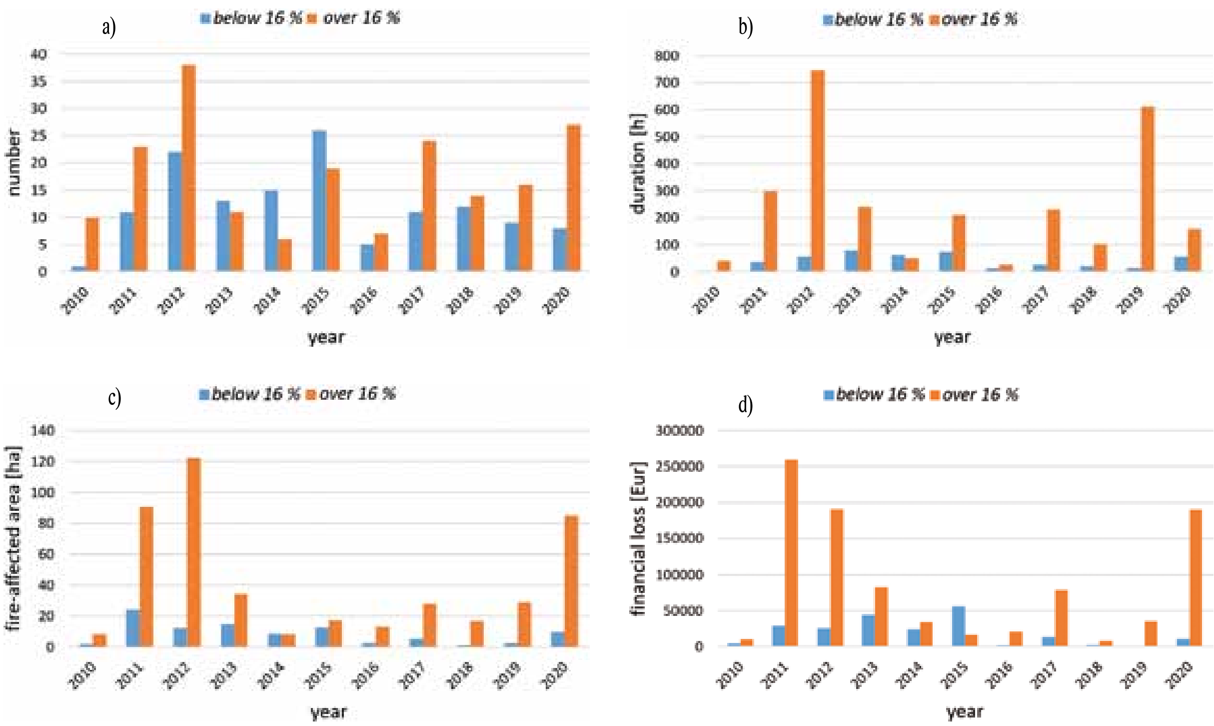

Fig. 2. Statistical data of forest fires in state forests of the Slovak Republic in 2010–2020, according to slope gradient: a) number of forest fires; b) duration of forest fires; c) fire-affected forest area; d) financial loss to forests.

Table 1. Fires in state forests of the Slovak Republic in 2010–2020.

Slope gradient	Forest fire (2010–2020)			
	number	duration [h]	fire-affected area [ha]	financial loss [Eur]
Below 16%	133	444	95.4	211 063.45
Over 16%	195	2723	452.5	927 373.93

Forest fire fighting should begin immediately after completing the fire line. In many cases, the fire-fighting can start already during the construction of a fire line, in the phase of establishing an initial fire attack. A forest fire will not be under control below the fire-fighting operations ensure that spread of forest fire in the area is brought to a halt. Fire extinguishing with water can be carried out using fire-fighting appliances (CAS), fire-fighting buckets or with the use of long-distance water supply hose pipes. But it is important to remember that the success of firefighting does not depend on the amount of water supplied to the seat of forest fire but on whether it is used efficiently (Majlingová et al. 2018).

Forest fire needs to be put out as quickly as possible using available resources while in its early stage. If a forest fire is not quickly extinguished, it can spread dangerously fast, when the forest fire front turns into a several kilometers long front with dangerous and uneven fingers of fire. The width, height, and rate of a forest fire, just like its extent, create huge natural force, which destroys everything that stands in its way and can pose a threat to human settlements and lives.

The following actions must therefore be taken in extinguishing forest fires:

– find and localize the forest fire,
– extinguish seats of forest fire within localized fire area,
– protect the seat of forest fire from possible spreading to the surroundings.

3. Fire-fighting adapter DATEFF

The need to transport water to the nearest intervening fire brigade has become a basic prerequisite for the idea behind designing a suitable fire-fighting device. The most appropriate and alternative solution based on this assumption is the use of forestry machinery. The starting point for this design was a definition of superstructure carrier providing maximum slope accessibility and mobility in a forest terrain. The utilization of available machinery used in the forestry industry, without further need to modify its construction or develop new machinery, was another important criterion. When accepting the basic requirements in relation to a workability in terrain, forest wheeled skidders (LKT) came into consideration as base machines. These base machines are primarily designed and intended to work in a difficult forest terrain. (Hnilica et al. 2020) Considering their construction and use, LKT base machines with hydrostatic energy transmission are suitable for driving adapters for the mechanization of work in the cultivation and protection of the forest. However, basic forestry-technical requirements for designing adapters should be considered, too. In particular, cost-effectiveness, extensive applications under different conditions, easy and fast installation on LKT, optimum distribution width, operation by the tractor driver from the cab, provision of drive slip in case of fixed obstacles, adequate noise levels, the minimal transmission of vibration to the operator (driver), utilization of domestic construction and spare parts, components and materials, ecological suitability, sufficient level of occupational safety and health protection as well as sufficient performance (Hnilicová et al. 2018a, b).

The main task of LKT is to move wood from the forest to the place of further manipulation. Its basic working algorithm changes in the case of a transport of an extinguishing agent. Space remains, but the direction of movement changes. For this reason, the DATEFF fire-fighting adapter was designed according to the concept of utilization of the base machine (LKT) as a carrier of a fixed superstructure for water transport (Fig. 3).

When fighting a forest fire, all research results must be reconciled with the tactical and technical abilities. These results require the knowledge of:

– principles of the forces and resources deployment tactics,
– availability of the base machine (LKT),
– design and technical limitations of the base machine (LKT),
– tactical and technical abilities (TTA) of fire-fighting equipment.

Fire-fighting tactics evaluates and processes the methods and the procedures of fire brigade intervention services in forest fire extinguishing, the rescue of persons and property. Even though fire-fighting tactics evaluates the results of growth and extinguishing of forest fire, it does not provide a complete solution or operating procedures of fire interventions. Fire-fighting tactics include the model situations and outcomes for commanding incident and operation of fire brigades in specific cases of forest fire by an incident commander.

Basic TTAs of the DATEFF fire-fighting adapter are indicated in [26], which shows the construction with principal dimensions.

The technical parameters of the fire-fighting adapter DATEFF are:

a) b)

Fig. 3. Fire-fighting adapter for: a) LKT 81; b) LKT 150.

- water volume max. 2,000 L,
- empty adapter weight 650 kg,
- weight of adapter with full tank and additional equipment 2,688 kg,
- possibility of filling by means of the C 52 filling neck on the side of the adapter (own pump, floating pump) or from above, after uncovering the closing lid (Bambi bag).

4. Use of fire-fighting adapter

The deployment of the adapter makes use of all tactical abilities of a base machine LKT, which arise from its design for operation on paved and unpaved roads (the part of forest transport network) and driving in an inaccessible terrain (off the roads) that cannot be reached by other types of forest fire extinguishing machinery. In addition to its travel and mobile abilities, the unique equipment of base machine LKT can be used for an intervention activity for the purpose of landscape modification, especially its front blade.

As forest fires represent a relatively dangerous situation, only firefighters with a relevant fire certification and persons authorized by the incident commander have permission to enter the forest fire site in Slovakia. Operators of LKT with the adapter can operate directly at the site of the forest fire only with the approval of the incident commander and according to the instruction given by the commander of the intervening fire brigade. The LKT operators must be eligible for driving this type of vehicles. In the case of countries where the participation of skidders and operators in forest fires is not legally allowed, we would recommend for each forest district to ensure that at least two operators of such machines are trained to be available in the event of a forest fire.

Regarding its design and technical parameters, the proposed DATEFF adapter can be employed operatively and tactically as:

- Fire-fighting mobile device
- Stationary device
- Alternative device

4.1. Fire-fighting mobile device with a base machine LKT

Deployment of the machine as a mobile emergency water tank

This type of deployment can be performed in extinguishing fire seat but also as a support of firebreak construction, using the front blade, in preventing the ground forest fire from spreading in the form of:

- with a nozzle operated by machine operators (Fig. 4),
- with a sprinkler platform (fire-extinguishing bar) on the front blade (water tank interconnected with

Fig. 4. DATEFF as a mobile water tank.

Fig. 5. DATEFF as water tank.

the blade in the front part of LKT through the motor pump).

Transport of extinguishing agent (water) to the place of intervention

In this case, the fire-fighting adapter becomes a water tank (Fig. 5) for the replenishment of hand-operated fire pumps (extinguishing fire seats). Then, in accordance with the requirements, as a source of water to supply an offensive line after unrolling the hose. It is the part of a long-distance transport of water in the case of a difficult water source without a forest access road network.

Emergency transport of material in a difficult terrain

It may be a mobile device for emergency transportation of materials in an inaccessible terrain. In this case, the composite tank is removed from the protective frame (Fig. 6). The frame construction itself ensures the transport of fire-fighting equipment to the place of intervention.

4.2. Stationary device – an autonomous drive of the adapter enables to use it separately without a base machine

Part of the long-distance transport of water using the pond system

Movability and travel abilities of a base vehicle allow for transport of the adapter (Fig. 7) into the area of a water source, which is not available to regular vehicles.

Fig. 6. Frame construction DATEFF for transportation of materials.

Fig. 7. DATEFF as part of a pond system: DATEFF adapter; J1 – Jx bags of a pound system.

The integration of the pond system eventually reduces the distance of water transport. The utilization of the adapter pump (HERON EMPH 20) when replenishing the adapter with another floating pump (discharge head 80 metres with the flow rate 500 L/min) enables deployment to the system of ponds.

Water tank in a difficult terrain

The tank itself can be replenished with a Bambi bag by helicopter (Fig. 8). The adapter can also serve as a substitute for close ponds (bucket, type II).

Fig. 8. Filling the DATEFF tank with a helicopter.

4.3. Alternative using of device

Besides being used for fighting forest fires, the fire-fighting adapter can also be used for transport of water to forest nurseries (irrigation), freshly planted areas in the event of prolonged drought, filling of watering-places for forest animals and filling puddles in the dry season and cleaning of culverts.

4.4. DATEFF fixing

In case that LKT moves at the forest fire site, it is appropriate to have sufficient certification for the vehicle, so it could be operated safely (motor hull insurance or other insurance policies). Machinery owned by state forest authorities typically has this kind of insurance policy.

The main and essential problem that firefighters encounter during interventions in a forest environment is to make the site available to fire-fighting machinery, which follows from a diverse terrain and natural conditions. This fact places high demands on the experience and skills of firefighters and operators of fire-fighting machinery participating in forest fire extinction whether in the phase of fire line construction or extinction itself. When designing the adapter, its deployment speed posed one of the essential problems. It implies that installation works on LKT equipped with the adapter have a fundamental role considering the on-site deployment speed of the adapter itself. Total time to fill a water tank has been another important factor. The two methods of filling have been observed. One of them via the use of the HERON EMPH 20 motor pump, which belongs to the adapter, and the other through the Bambi bag containing 1,000 L (Fig. 10). Transport of the adapter to the place of the operating test was provided by a logging truck Scania CV AB. The adapter was put down from the loading surface by the hydraulic arm LOGLIFT F 108ST 96. Based on the results of time observations (5 process measurement), it may be concluded that the overall time of the LKT base machine deployment with the DATEFF adapter is relatively short. The overall time of installation is 35 mins. Consequently, it took 11 mins on average to fill the device with an extinguishing agent when using its own motor pump and 6 mins when using a helicopter with a Bambi bag containing 1,000 L. In our case, the resulting time value using a helicopter includes the time of the flight to the place of filling of Bambi bag with the mobile fire tank truck CAS 32 T815 equipped with a pump of an output of 3,200 L/min. Further data required for assessment of operational and tactical deployment of the adapter is a minimum time of tank release, hence its use during interventions. The tank can be released in 13 mins. This duration may increase depending on the operational and tactical deployment, for example, water fog fire extinguishing etc.

Fig. 9. Mounting of the supporting frame to LKT's rear log arch.

The actual installation of DATEFF on skidder does not require any special intervention to the vehicle construction. It involves the mechanical mounting of the supporting frame to LKT's rear log arch using screws (Fig. 9). The jointing location intended for the attachment of towing device is located on the rear log arch. After clamping of the supporting frame, LKT drives back to the tank and lifts the tank through the two hooks with a following mechanical locking (by extending pin) with the help of the LKT operator (Fig. 10).

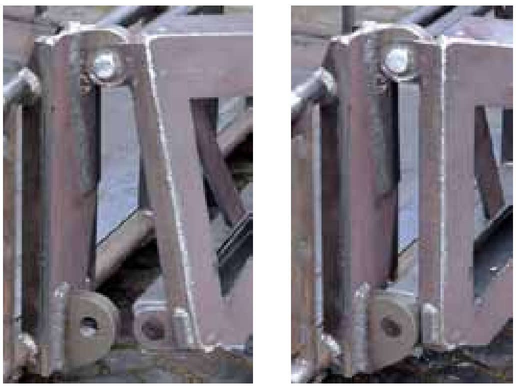

Fig. 10. DATEFF attachment system to the support frame.

4.5. Case study of DATEFF deployment under operating conditions

Assessment of a slope accessibility under operating conditions was one of the fundamental concerns regarding any adapter deployment. Different slope gradients have been observed using the LKT base machine loaded with a full tank (2,000 L) and half-full tank (1,000 L). LKT went uphill and after turning he returned the same way down. Selected time results of operating tests including the slope gradient, travelled distance and volume of the transported extinguishing agent (water) are listed in the Appendix 1.

The resulting values have been processed statistically using the regression and correlation analysis. The time needed for a transfer of a base machine with a tank to the place of intervention and its slope gradient has been assessed through this analysis when driving uphill and

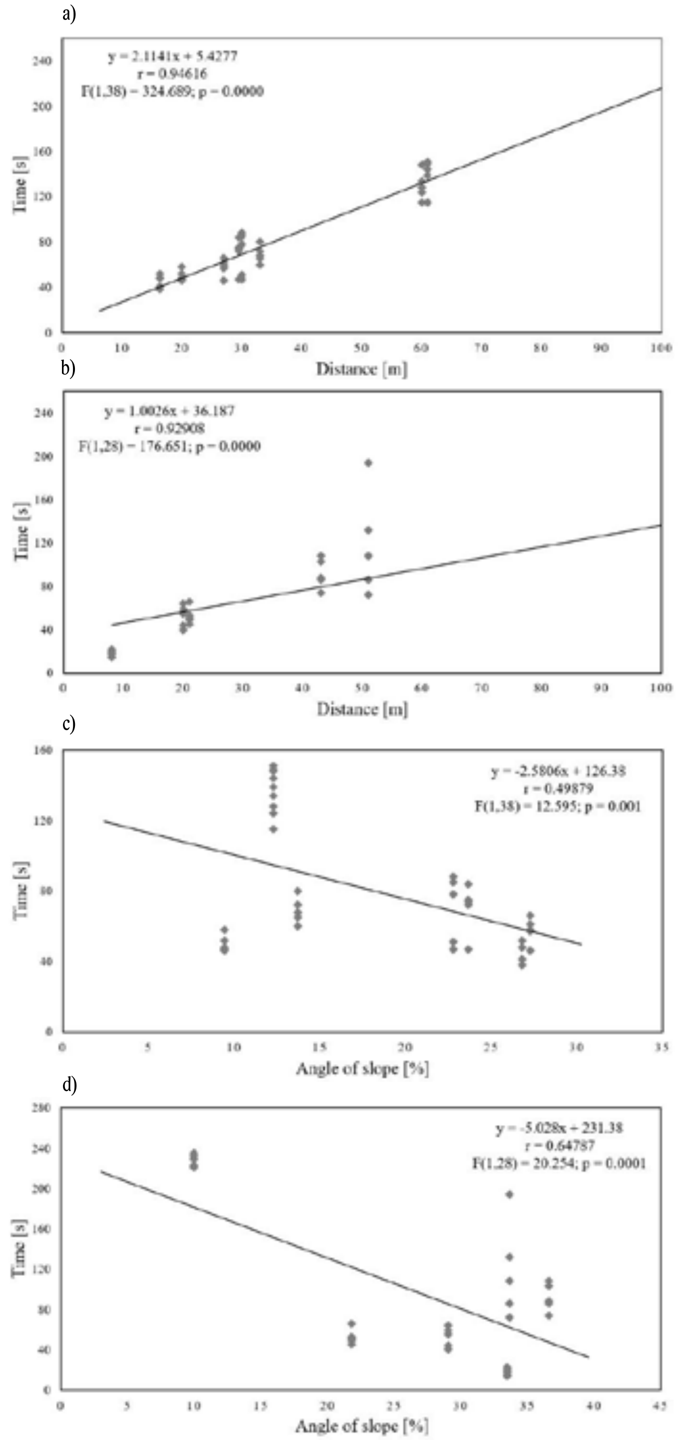

Fig. 11. Regression analysis of interdependence: a) the time and distance travelled (the full tank); b) the time and distance travelled (the half-full tank); c) the time and slope gradient (the full tank); d) the time and slope gradient (the half-full tank).

downhill. Each graph shows the interdependence of time and distance travelled by the adapter with a full tank (Fig. 12a) and half-full tank (Fig. 12b). These graphs further show the interdependence of time and slope gradient when riding with a full tank (Fig. 11c) and half-full tank (Fig. 11d).

In conclusion, the statistically processed results of operating tests show that the deployment speed of the fire-fighting adapter from its import to intervention is relatively short. Time depends to a large extent on the distance travelled and on the volume of loaded extinguishing agent. The results of ANOVA for full tank ($F(1,38) = 324.689$; $p = 0.0000$) (Fig 11a) and half-full tank ($F(1,38) = 176.651$; $p = 0.0000$) (Fig 11b) have confirmed important influences of distance traveled on the speed of intervention (time) during a forest fire. Of course, the delay increases with a full tank. LKT travels 100 m distance with a full tank (2,000 L) in 3 mins 37 secs, while LKT loaded with 1,000 L of extinguishing agent travels the same distance in 2 mins and 16 secs. The results of the regression analysis shown in figures 12c and 12d cannot clearly confirm the hypothesis that the intervention speed (time) increases with the rising slope. The results of ANOVA for full tank ($F(1,28) = 12.585$; $p = 0.001$) (Fig 11c) and half-full tank ($F(1,28) = 20.254$; $p = 0.0001$) (Fig 11d) haven´t confirmed important influences of the effect of slope on the impact rate (time) during a forest fire. These results rather indicate an opposite trend. The intervention time decreased with the increasing gradient. However, the effect of the distance travelled needs to be considered as well. That is why multiple regressions (Appendix 2 and 3) were carried out, which served to determine whether there is an interdependence between distance, slope gradient and intervention speed (time). It is assumed that the higher the slope gradient and the longer the distance, the longer will be the deployment time of the adapter during the actual fire-fighting intervention. The null hypotheses tested within this analysis are related to the significance of the regression constant and coefficients: the null hypothesis asserts the insignificance of the corresponding coefficients while the alternative hypothesis asserts its significance. These assumptions are evaluated using the P–value. The P–value for Intercept (regression constant) is $0.521 > 0.05$. This indicates that the regression constant is statistically insignificant. The P-value for the b_1 regression coefficient is $0.97 > 0.05$, which confirms the insignificance of this coefficient. The P-value for the b_2 regression coefficient is $1.34*10^{-17} < 0.05$, which confirms the significance of this coefficient. Since the regression constant as well as the slope gradient independent variable are statistically insignificant, they should be eliminated from further calculations.

The first part of the Regression Statistics includes the results relating to correlation analysis. The Multiple R–value (correlation coefficient) is equal to 0.947. The closer this value is to 1, the stronger the correlation. Our example deals with a high level of closeness of the relationship between the distance and intervention speed (time). The R Square value is a value of the determination coefficient; in our calculation its value is equal to 0.896. When multiplied by 100, this value informs that the chosen regression function explains the distance variability to around 90%, while the remaining part represents an unexplained variability, the influence of random factors and other unspecified impacts.

Models were selected correctly.

The form of the regression equation for the full tank would be (Appendix 2):

$$y = 6.12 + 0.01x_{angle} + 2.1x_{dist} \qquad [1]$$

The form of the regression equation when carrying a half-filled tank would be (Appendix 3):

$$y = -20.1 + 1.67x_{angle} + 1.19x_{dist} \qquad [2]$$

If the slope gradient is considered, then the driving time that takes it to travel the 100 m distance with a full tank (2,000 L) can be calculated according to the relation (1). The LKT travels this distance at a gradient of 20% in 3 mins 36 secs and needs the identical time of 3 mins 36 secs at a gradient of 30%. The driving time in which it travels 100 m with a half-filled tank (1,000 L) can be calculated according to the relation (2). The LKT travels this distance at a gradient of 20% in 2 mins 12 secs and needs a similar time of 2 mins 29 secs at a gradient of 30%. According to these results, it can be assumed that the slope gradient and the speed of adapter deployment have practically no effect. The periods in question were assessed for driving uphill. The movement of the LKT base machine in the terrain is characterized by slow transmission at maximum performance. This seems to cause that the slope gradient, in this case, is negligible as far as intervention speed is concerned. It is particularly important in terms of the slope-related accessibility of the machine. That is, what slope the LKT with the DATEFF can traverse when driving uphill.

5. Advantages and limits of adapter use

The adapter attached to LKT riding with a full tank has had a slope gradient limit of 30%. In the case of a half-loaded tank, it can be said that LKT has a slope gradient limit of 40%. These are mostly the limits for uphill driving. Limits for downhill driving will be higher. This results from the technical solution of DATEFF's position on the rear log arch. Operational tests of this solution resulted in decline in the adhesion (lifting of the front axle) during uphill driving at slopes with gradient exceeding 40%. Based on the above facts, the slope in question needs to be understood as the upper limit for driving an LKT with a full tank considering this design solution. However, when driving downhill we assume passability of even steeper slopes. This will be subject to further research and testing under operational conditions. The

DATEFF-adapted LKT delivers good maneuverability in forest terrain. The LKT's bending frame enables turning with minimal space requirements. This fact has also been verified under real operating conditions. This represents another significant advantage over CAS, which can carry large amounts of water, but their manoeuvrability is limited. In most cases, CAS can travel only along paved surfaces free of any terrain obstacles. On the contrary, existing firefighting equipment with good manoeuvrability in difficult forest terrains cannot transport a larger amount of water (max. 200 L). While the conventional firefighting equipment is mainly designed for the forest transportation network outside the actual undergrowth, LKT is a suitable base machine especially because it meets the technical parameters for movement along the skid trails within the undergrowth.

In practice, our proposed solution design has no such limitations. LKT has special technical parameters for the movement and transport of loads in the forest. There are some limitations resulting from the adapter design, which have been identified after operational testing. However, all these limitations can be eliminated after some modifications. This mainly concerns greater chamfering of the rear part of the protective frame. LKT equipped with DATEFF can travel on unpaved roads, sloping tracks as well as undergrowth itself. In the future research, it will be crucial to focus on the rotation and movement of LKT along the hill. Operating tests, observations, and consultations with LKT operators have been a prerequisite for improving these parameters. This follows from the technical and performance specifications of base machine LKT. Counterweight installed on the front blade for example in the form of a 500 L tank could improve the stability of a base machine when riding up the slope. It was assumed that the front axle had been lifted at limited gradients and therefore its centre of gravity was displaced. This issue is currently being worked on together with subsequent tests right under operating conditions.

Of course, the availability is also affected by soil cover, though, in this case, the ground was assumed to be dry since the forest fires mostly occur during the dry season. Another factor includes the specific type of a base machine LKT. In this case, it was the older type LKT 81, which is currently widely used in forestry operations (the state-owned or private ones). The use of a more powerful LKT could in theory increase the slope availability.

Technical design of the DATEFF fire-fighting adapter with the autonomous control system enables the integration with similar base machines made by other manufacturers. Because of the different design of inclinable rear log arches, the supporting fastening system will need to be resolved for the anchorage of the fire-fighting adapter on a base machine. The draft of design ideas for such a universal fastening system is currently being worked on.

Following the conclusions of operating tests and subsequent analysis of its deployment in forest fires, the basic technical characteristic of the DATEFF adapter that affects its operative and tactical deployment can be formulated as:

- fibreglass water tank with breakwaters preventing the uncontrolled spilling of an extinguishing agent during transport,
- drain/inlet opening on the bottom of the tank with shut-off valve and "C" 52 mm semi connector,
- removable tank cover for internal technical maintenance and replenishment with extinguishing agent by aerial vehicles from the air (Bambi bag),
- protective frame that ensures superstructure handling (tank transfer, tank lifting) and transport of superstructure at the scene of a fire (semi/full suspension) during transport to a place of destination,
- protective frame ensuring the import of firefighting equipment in inaccessible terrain, after removing the composite tank,
- supporting frame for the anchorage of the adapter to the inclinable rear log arch of LKT.

At present, the representation of base machines of the LKT type predominates in the forests of the Slovak Republic, but they do not have a similar superstructure. Due to its construction, the superstructure is quickly adaptable to the LKT base machine. Field tests have shown that the LKT with a filled fire-fighting adapter is capable of driving and maneuvering in mountainous terrain. We think that the prototype of the fire-fighting adapter will be benefit for forestry practice in protecting the forest from forest fires.

6. Conclusions

The design of the fire-fighting adapter DATEFF and speed of deployment make it ideal for liquidation of forest fires in difficult terrain conditions Slovak forests. At present, when forest fires occur, it is often quite complicated in forest conditions to provide sufficient technical support for the rapid prevention and elimination of forest fires. This fact is largely eliminated by the proposed fire-fighting adapter. Based on operational tests, cooperation with HaZZ SR (Ground Forest Fire Fighting Modules) and forestry operation, the following conclusion was reached. The fire-fighting adapter will provide sufficient technical support in difficult terrain conditions for water transport logistics in order to quickly prevent the spread and liquidation of forest fires.

The fire-fighting adapter is designed for forest wheeled skidders that achieve a slope accessibility of 40%. They can work on the stand, overcome obstacles and their real number and availability in all subjects of forests. Within these conclusions they were developed operational and tactical characteristics of the fire-fighting adapter DATEFF and possibilities for deployment and use in forest fires.

Due to its design, the fire-fighting adapter is a suitable technical means of combating fires in a forest environment. The new design of the rear folding shield of the new LKT types has to some extent limited its use for these types. For this reason, it is necessary to solve a more universal system for connecting the adapter to the base machine. We want to deal with this technical solution in the near future in cooperation with the manufacturer of base machines. A suitable accessory will be to fit the LKT front blade with an additional water tank to ensure increased stability. These facts resulted from operational tests. In the future, we also want to focus on a partial modification of the adapter design in order to remove partial dimensional restrictions.

Acknowledgments

This work was supported by "Agentúra na podporu výskumu a vývoja MŠVVaŠ SR" under the contract number APVV-14-0468.

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Appendix

Apendix 1. Time results of operating tests including the slope gradient*.

Slope gradient		Time		Distance	Volume of transported
[°]	[%]	[min]	[s]	[m]	water [L]
5.4	9.45	0:48	48	20	2,000
7	12.28	2:04	124	60	2,000
7	12.28	1:55	115	61	2,000
7.8	13.7	1:05	65	33	2,000
12.8	22.79	0:47	47	30	2,000
13.3	23.64	0:47	47	29.5	2,000
15	26.79	0:38	38	16.3	2,000
15.25	27.26	0:48	46	27	2,000
17.1	30.76	0:00	0	—	2,000
5.7	9,98	3:49	229	200	1,000
12.3	21.8	1:06	66	21	1,000
16.2	29.05	0:40	40	20	1,000
16.2	29.05	0:50	55	20	1,000
18.5	33.46	0:15	15	8	1,000
18.6	33.65	1:12	72	51	1,000
18.6	33.65	1:26	86	51	1,000
18.6	33.65	3:14	194	51	1,000
20.1	36.59	1:26	86	43	1,000
20.1	36.59	1:14	74	43	1,000
23.1	42.65	0:00	0	—	1,000

* To assess the abilities of operation and tactical deployment of the fire-fighting adapter, operating tests have been performed in the department of the University Forest Enterprise in Zvolen. In particular, the Bieň forest area (part Jačmeniská 48°37'13.6336702"N 19°3'39.9746132"E) falling within the Budča forest administration unit. The measurements were performed before the ride with a full tank (2,000 L) and half-full tank (1,000 L). Time observation was carried out by 3 workers. Driving time was captured by a stopwatch with a precision of seconds. The beginning and the end of a ride were observed by eye. The slope gradient and length were measured using the TruePulse 360B laser measuring device.

Apendix 2. Multiple regression and correlation analysis of interdependence the time on the angle of slope and the distance travelled (the full tank).

Regression Statistics						
Multiple R	0.94673866					
R Square	0.8963141					
Adjusted R Square	0.89070945					
Standard Error	11.7220379					
Observations	40					
			ANOVA			
	df	SS	MS	F	Significance F	
Regression	2	43948.94663	21974.47	159.9235	6.17753E-19	
Residual	37	5084.028367	137.4062			
Total	39	49032.975				
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	6.11883089	9.454125147	0.647213	0.52149	−13.03704622	25.274708
angle of slope	0.01060087	0.317421066	0.033397	0.973538	−0.632555305	0.65375704
distance	2.09999426	0.13708707	15.31869	1.34E-17	1.822229469	2.37775904

Apendix 3. Multiple regression and correlation analysis of interdependence the time on the angle of slope and the distance travelled (the half-full tank).

Regression Statistics						
Multiple R	0.93856662					
R Square	0.88090729					
Adjusted R Square	0.87208561					
Standard Error	25.7139909					
Observations	30					
			ANOVA			
	df	SS	MS	F	Significance F	
Regression	2	132052.8482	66026.42	99.85707	3.34541E-13	
Residual	27	17852.6518	661.2093			
Total	29	149905.5				
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	−20.077363	28.75000764	−0.69834	0.490934	−79.0675062	38.9127799
angle of slope	1.67109827	0.833608305	2.004656	0.055123	−0.039324684	3.38152123
distance	1.18518478	0.11590925	10.22511	8.79E-11	0.947358645	1.42301092