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Characteristics of Forest Fires and their Impact on the Environment

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We can hear about large scale forest fires in the media from several areas of the European Union almost every year. A large forest fire causes a serious impact on the environment, determining its future for decades. Prevention of forest fires is one of today's most important tasks as well as appropriate preparedness for effective fighting against them. To do so, it is vital to have detailed knowledge on the characteristics of different forest types and their environment, their ecosystems and food-chains, and technical information on the properties of forest fires and their effects on the different elements of the environment and lessons learned from previous cases.
Based on gathered information of past events authors have provided a complete system of forest fire categories by their size, type, risks and consequences. We investigated the detailed impacts of forest fires on the different elements of the environment.
The content of this paper may help the work of the sylviculturists and other agrarian experts involved in the rehabilitation processes of forest ecosystems after large-scale forest fires.
Keywords: *ecosystem, environment, fire-fighting, forest fire*

Introduction

The number of forest fires due to climate change is continuously growing nowadays. With the expansion of the European Union (EU from now on) appropriate defence against forest fires becomes more and more important. The number of annual forest fires within the EU is between 50–70 thousand, touching 3–5 thousand square kilometres and causing damages in millions of Euros. It was recognized by environmental experts of the EU that forest fires cause significant ecological, economic and social problems in many European countries with possible long term consequences to the natural environment and the economy. [1] Member states of the EU have created common directives[3] and national regulations for the protection of forests and prevention of forest fires and carry on different scientific research in this topic. [2] Planning of environmental security has become a primary task. [3] Investigation of forests' structures, proper knowledge on the development of forest fires and their impact on the environment can help in the protection against forest fires and in fighting against large scale forest fires, which is a complex and difficult task for defence organizations and personnel. [4] [5]

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3 Council regulation (EEC) NO 3529/86 on protection of the community's forests against fire

Reasons of Forest Fires

When drought causes dryness, or after every large scale forest fire the attention turns to the forests, to the investigation of natural fires' prevention, fire-fighting, its technical and organizational issues and the reasons and consequences of forest fires.

Forests can be divided into 3 categories by the types of their trees and undergrowth: [5]

- deciduous forest (oak, beech, poplar trees);
- coniferous forest (pine trees, juniper bushes);
- mixed forest (mixture of deciduous and coniferous species).

The fires' ignition and spreading parameters of forest types are different. Undergrowth of a deciduous forest has more humidity in general, so it does not catch fire easily. But there is a high resin content in the leaves and trunks of coniferous trees causing easier kindling and burning. These forests are dryer, in general. Approximately 75% of forest fires happen in pine woods and only 25% in deciduous forests. [5] Concerning the reasons and consequences of forest fires the following categories can be investigated in details:

- abiotic factors;
- biotic factors;
- economic factors;
- human factors.

Abiotic factors: From the elements of the climate, the amount of precipitation and the temperature are the key components in the development of forest fires. Additional parameters can be:

- amount of daily sunlight;
- atmospheric circumstances;
- prevailing wind speed and wind direction.

Relief forms on the surface are also important, because fires in general can rapidly spread from lower terrains uphill. Also ragged surface with rifts, rocks or watercourses can stop vegetation fires.

Biotic factors: Populations of species and interactions among the individuals are the key aspects during forestation to select proper tree species. It is especially important in our country to handle coniferous species with care, because they are affected with fires the most, and have influence on the range and seriousness of forest fires.

Age of forests, quality and quantity of undergrowth and thickness of dead fallen leaves are also important biotic factors.

Economic factors: Environmentally friendly, secure and responsible sylviculture plays an important role, because it has a great role in minimizing development and spread of forest fires. Neatness of forests, clearness of forest passes, tracts and trenches are also important, because forests become more opened and transparent this way. [6]

Woodcutting and burning of cutting waste also affect forest fires. Regulated and sustainable economics is important, [29: para 2] together with the observation of rules and capabilities for effective fire-fighting.

Human factors: One of the most common reasons of forest fires is inappropriate human activity. Most of the forest fires start because of human faults, carelessness or intentional fire-raising.

Most common human activities causing forest fires:
- forbidden or irregular firing;
- growing tourism by car or motorcycle;
- smoking in forests;
- burning of agricultural waste or stubble in the vicinity of forests.

Categories of Forest Fires

Forest fires can be divided into 4 categories in the forests of Hungary based on tree and other vegetation species:
- underground burning, peat fire;
- fire in undergrowth or dead fallen leaves;
- fire in seedlings and saplings;
- fire in trunks and shrouds.

Underground Burning

Underground burning can start in forests, where peat layers can be found beneath. In most cases under-composed organic material enriched in the upper layers of soil burns without flames. These types of fires are rare, but when they happen, they can last long and can spread onto large territories. Their spreading speed is very slow, some centimetres or maximum a few meters per day. Reasons can be self-ignition or fire in undergrowth.

Fire in Undergrowth

Flames spread directly on the surface vegetation (dry grass, dead fallen leaves, twigs, etc.) burning the lower parts of the trunks and roots above the surface. Fires in undergrowth can be divided into 3 categories based on their spreading speed *(Vt)* and flame height *(Hf)*:
- week, if $Vt \leq 1$ m/min and $Hf \leq 0.5$ m;
- moderate, if $Vt \leq 1–3$ m/min and $Hf \leq 0.5–1.5$ m;
- strong, if $Vt > 3$ m/min and $Hf > 1.5$ m. [5]

The spreading speed greatly depends on wind speed and wind direction. Spreading in the wind direction is 6–10 times quicker than in headwind.

Based on their duration we can distinguish running fires and persistent fires. Running fires burn down the dry vegetation close to the surface. Plants with higher water content and deeper, humid soil layers are not affected. Running fires can be formed by high wind speeds and spread rapidly.

Persistent fires in undergrowth spread slowly because of a low wind speed and not only surfaces are burned, but fires also spread in the upper mould layers with glow and dense smoke. Skins and roots of trees are also heavily damaged during these types of fires and small seedlings, saplings and bushes burn totally. Persistent fires in undergrowth can spread even onto the trunks and shrouds of larger trees.

Fire on Seedlings and Saplings

In case of persistent fires in undergrowth, additionally smaller trees, bushes can catch fire. In sapling areas of forests in the presence of heavy winds spreading speeds can reach 500 meters per hour. In most cases spreading has an irregular form; the burned area grows radially. [5]

Fire on Trunks and Shrouds

During dry or drought periods, fires in undergrowth can grow to fires on trunks and even on shrouds. Their common feature is that fire spreads not only on the ground, but on trunks, leaves and shrouds of bushes and trees, with the burning of leaves, twigs and bigger arms of the trees. As a consequence, trees die in most cases.

Additional fire in undergrowth can be formed during fires in shrouds, this time the burning of undergrowth is part of the shroud fire. Three categories can be described based on horizontal speed of fire spreading *(Vt)*: [7]

- week, if $Vt < 3$ m/min;
- moderate, if $3 \leq Vt \leq 10$ m/min;
- strong, if $Vt > 10$ m/min.

Based on their behaviour in time it can be also divided into two groups: running and persistent shroud fires. A running shroud fire can be formed in case of a heavy, stormy wind. Spreading of fire happens with “jumps” among shrouds this way being far ahead of the accompanying undergrowth fire. In general, the fire starts within the undergrowth, than lower parts of the shrouds heat up, begin to burn, and the fire spreads in the shrouds by the help of the wind.

In case of persistent shroud fires, they spread among the shrouds, but the ground surface burns down, too. They can be formed with weak winds. After this kind of fire trees are heavily burned, charred, and can fall down.

When grouping forest fires, we have to make differentiation based on the types of affected territories. Because of their different features, we can talk about forest fires on plains and in mountain areas. Forest fires in mountains are extremely dangerous, because of the high resin content of coniferous trees the speed of spreading can be 2–3 times quicker than in deciduous forests.

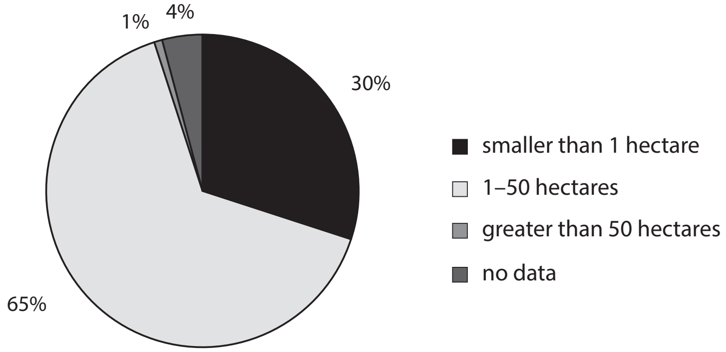
Fighting against forest fires in mountains can be more difficult because of the rough terrain and rare water sources.

Size of Forest Fires

Forest fires can also be categorized by their sizes, based on the affected areas. In general, the territories of forests are greater in mountains and hills than in marshy plains. We can talk about:

- small forest fire, if size smaller than 1 hectare;
- average, if size between 1 and 50 hectares;
- large, if size greater than 50 hectares.

The following graphics (Graph 1) shows the relative numbers, based on the data of different sized forest fires from the last 10 years in Hungary.



Graph 1. Sizes of forest fires in Hungary.
(Source: based on the data of NFCSO,[4] completed by the authors.)

Effects of Forest Fires to the Environment

Effects of Forest Fires to the Movements of Air

Differences in air pressures between geographical points are equalized by significant and continuous movements of air. [8] This movement shows a form of unperturbed flow in the absence of external effects. A forest is an obstacle, so the moving air changes its direction and form after a collision.

It can be observed on the windward side of the forest that wind blows through the fringe of the forest depending on the wind speed, the density of the forest and the surface relief. If the wind direction is perpendicular to the fringe of the forest, it always blows through a larger area. On the opposite side of the forest, a shadow zone can be observed, where the air movement is less intense. Its size depends on many factors, in general 6–10 times larger than the effected forest area. Wind speed beyond the shadow zone is equal with its speed in front of the forest. [9]

In addition to the above mentioned effects, the surface relief, large objects on the ground, vegetation, effects of large fires, and other factors can disturb the unperturbed wind flow resulting in whirling movements. This is the so called “turbulence” that has significant effects on the use of fire-fighting aircraft in low altitudes in case of forest fires, and on the spreading of smoke.

Mechanical turbulence. Unevenness in the shroud level of the forest, cuttings, clearings and the fringe of the forest together force the disturbed air into a whirly movement with horizontal axis. These mechanical turbulences in low altitudes can cause danger to the fire-fighting aircrafts, but their predictable presence and moderate airflows allow the pilots to handle them securely. [10]

4 National Food Chain Safety Office; official website: www.nebih.gov.hu

Figure 1. Formation of mechanical turbulence.
(Source: based on the work of Á. Restás [10: 48], completed by the authors.)

Thermic turbulence. Because of vertical temperature differences in the atmosphere the pressure difference causes an airflow blowing vertically upwards in a spiral, whirly movement. The speed of the vertical wind depends on the temperature gradient.

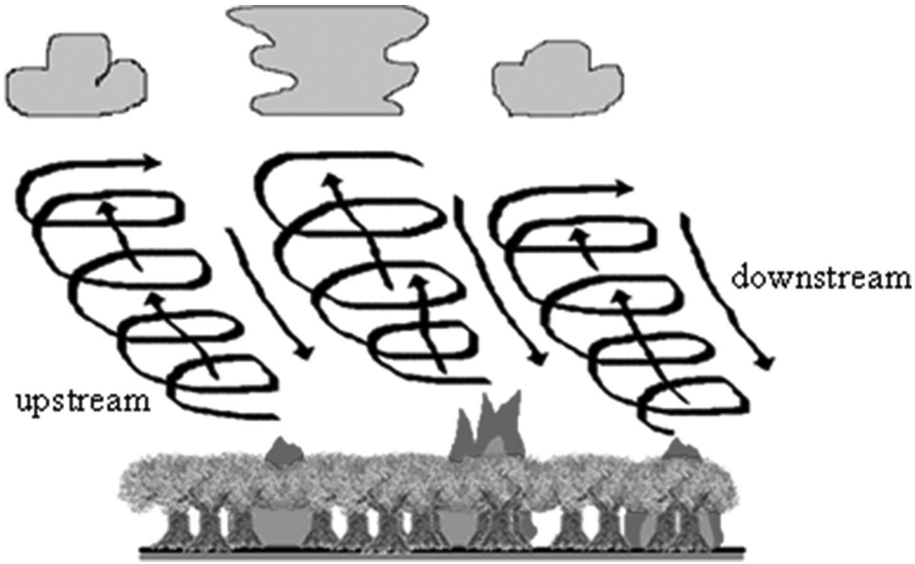


Figure 2. Streams of thermic turbulence.
(Source: based on the work of Á. Restás [10: 49], completed by the authors.)

Calculation of the energy of thermic turbulence is difficult. In general, it is very dynamic, able to change its direction very quickly and it is very unpredictable. Intensive upstreams can be accompanied by nearby downstreams with the same intensity. Between the very intensive upstreams and downstreams the so called "wind openings" can be formed. This is extremely dangerous for fire-fighting aircrafts! If the forms of upstreams and downstreams are visible (smoke), their areas must be evaded during the flight both towards the target and in the opposite way. The only advantage of the intensive airflows is that together with the hot air it also transports the smoke. This way we can collect more accurate data during air reconnaissance about the place, size and behaviour of the fire, and less smoke means better sight in general.

Mixture of mechanical and thermic turbulences. The above described types of turbulences do not come up in their pure forms in case of a forest fire due to the presence of wind. By the combined effect of wind and fire the mixture of the two types and its separation for different zones can be observed. Because of the unpredictability of the instantaneous movements of turbulent airflows low altitude flights with fire-fighting aircrafts can become very risky and only the experience of the pilots can help to compensate this.

Formation of bubbles. In case of no wind, with the development of a forest fire, a very unique type of airflow can be observed. Heated air over the fire forms a bubble and lifts from the surface as a big ball without developing a continuous airflow. Cold air replaces the bubble; it is also heated quickly and goes up in the same way. This is a rapid procedure repeating with a pulse.

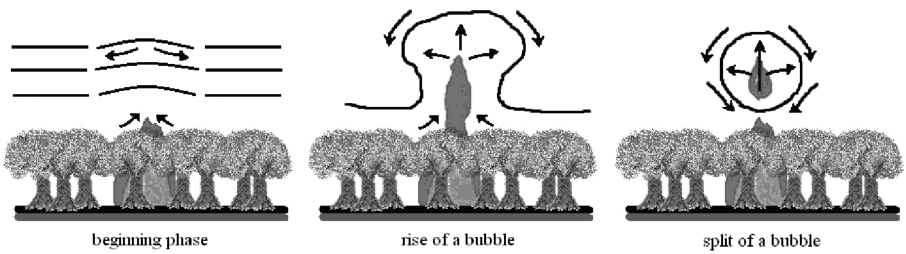


Figure 3. Phases of bubble formation.
(Source: based on the work of Á. Restás [10: 49], completed by the authors.)

The forming bubble looks like the smoke puffing up from a steam locomotive. Danger of the bubbles comes from their sudden formation and termination. In one moment circumstances can be ideal to fly over the flames with a fire-fighting aircraft while some seconds later nothing can be seen because of the heavy smoke.

Environmental Hazards of Forest Fires

Environmental hazards of forest fires must be investigated in order to prevent further fires, to develop appropriate techniques for fire-fighting and for the proper restoration of damaged, burned forest areas after forest fires. [5] In the following we will describe the harmful effects of forest fires on different elements of the environment in a timely manner.

Either the fire is natural or man-made; it can disturb and strongly change the structures and functional processes of forest ecosystems. Consequences of fires are hard to describe in general, because they are functions of their characteristics. Some of these are: frequency of their repetition in time, volume of fires, their intensity (fire on dead fallen leaves, on shrubs or on the tree-tops) and duration, in which season were they occurred, climatic circumstances during fires and precipitation intensity before and after the fires.

Forest fires can have very serious economic and environmental impacts. There are different ways to measure the economic impact; [11] [12] [13] however measuring the environmental impact is very difficult.

Environmental impact of forest fires can be categorized in many ways. Classification is important, because certain harms could be prevented together in the future with the use of a common method by the recognition of similarities. The base of the classification can be their duration, the size of threatened territory, their harmful effects on the vegetation, animal kingdom, soil, air, water or other distinguished categories.

Vegetation

One of the reasons of raising frequency and seriousness of forest fires is the desiccation process emanating from "global climate change". [14] As a consequence of this desiccation process, the amount of annual precipitation in Hungary decreased by approximately 100 millimetres in the last 4–5 years. [15] The humidity of plants has also decreased, and this resulted in a lower flash-point of the vegetation. Resistance of species is different; some plants are regenerating faster after a forest fire and so will spread on larger territories than before. [16] Vegetation species that cannot regenerate themselves must be replanted to restore ecological balance in the forest. [17]

Effects on boreal plants. Fires have less intensity on parklands mostly with frondiferous trees and bushes, where burnable, dry material is in a lesser amount so burning can be only partial on plants and on the terrain. This means that one part of the branches of trees and bushes survives while the other falls because of the heat stress. These trees and bushes have a chance to regenerate depending on the damage cropping up from their trunks, branches, sprigs, stumps or roots. Forest parts dense in pine-tree and juniper are more sensitive to fire and can strongly feed it. The fire can grow tall here quickly causing total destruction. Tine-trees and junipers totally burn away together with other neighbouring frondiferous trees, bushes and perpetuals. Perpetuals, frondiferous trees and bushes living together with junipers burn more or less, and in the vicinity of heavily burning junipers they can suffer total burning destruction, so all their parts above the ground are damaged by the fire. After the fire the environment is lifeless for a year. Then different apexes, sprits start to grow very quickly and in a large amount, the area grows green proving the surviving and renewing capability of nature even after a fire catastrophe. Rejuvenation of the vegetation, natural greening of the burned terrain can happen also with seeds. Seeds can survive fires in the soil or can come from neighbouring territories with the wind, or by the birds, insects or other animals. Sprits and apexes of some plants fruit soon and producing lots of seeds to ensure their proliferation. Pines however cannot regenerate after heavy burning, their rejuvenation comes very slowly with their seeds only, and so settling them back needs human help.

Effects on non-boreal (herbaceous) plants. Herbaceous plants are necessary to cover and protect soil. After a fire, rejuvenation of the vegetation, growing of plants start only next spring. For the meantime soil remains uncovered so the Sun can burn, the wind can dry and rain can degrade it. This way remaining minerals from burned plants and part of the degraded topsoil can lapse to lower grounds to produce very favouring production environment there.

Herbaceous plants after a fire are regenerated in a vegetative way, with turions. Appearance of turions is very spectacular in a year. Every plant after a fire, even those species which are unwanted at the given ecosystem are completing a very important protection task. In their presence, the young, 1–2 years old arboreals together with surviving seeds and others from neighbouring territories can breed and settle back. So herbaceous plants are indispensable to cover and protect topsoil.

Animals

Direct effects of fires on animals can be:

- fires can destroy animals living on the territory;
- fires can change ecological features of the biotope this way becoming unsuitable for species living there before but helping to settle new species with different demands.

Extent of direct destruction effect for different species depends on their position in the zootaxy. In general the greater, quick moving mammals and birds can escape successfully to safer grounds. So their destruction rate is low, only younger, weaker ones die, but the young of birds nesting on the ground are heavily affected. Mortality is much greater within smaller or slow moving animals such as frogs, lizards, snails, spiders. Forest fires can cause dramatic destruction among their populations. Soil surprisingly has a good heat insulation effect, so ant-hills and larviforms of insects growing in the ground generally survive forest fires.

Indirect effects of fires, elimination or damage of animal biotopes cause more obvious, permanent changes in forest fauna. The reason is that most of animal species have greater specific demands concerning their biotopes than we can estimate based upon our first investigation of a forest environment.

Resistance of the fauna species is only limited by their escape capabilities and this depends on the spreading speed of the fire. In case of a high speed running fire even quicker, larger animals cannot escape. In general, nests and animal hideouts are totally destroyed in burned areas. This drives the local fauna to migration. Because of the destroyed vegetation and the replaced fauna, the balance of the micro environment upsets, and the local natural environment changes. [18]

Soil

Erosion of the soil speeds up after a forest fire due to partially or totally destroyed vegetation, the upper fertile soil layer can disappear. [19] [20] In absence of the cohesion power of fibrous root systems soil becomes loose and washable. [21] [22] After a forest fire soil can easily and quickly be washed by rains from hillsides. On plains, ash layers generated by the fire can be washed from the surface into the deep soil making the soil alkaline that leads to the extinction of plants that cannot tolerate alkalinity. [23] [24] A further problem is that the heat generated by the fire kills microorganisms useful to plants, so replacement of vegetation becomes slower.

Due to burning and scorching of seeds rejuvenation of the flora is only possible with newly arriving seeds into the soil. Those plants that cannot tolerate alkalified soil will die in a short time. This harm will be one of the obstacles against the restoration of the original ecosystem. The origin of the tree species is indifferent in the formation of the soil fauna diversity. The layer of the dead fallen leaves above the populations and physical-chemical parameters of the soil are more important. In general, populations of some natural, native soil fauna species are richer in numbers (in number of individuals and number of species also) than fauna of regenerated soils after forest fires.

An additional consequence of forest fires is that soil erosion can speed up due to partly or totally destroyed flora, this way topsoil can be heavily degraded or totally eliminated. After burning the parts of the plants above the ground fire does not stop, it slowly destroys in brand form even the roots, underground parts. This way the soil cohesion force of the roots disappears and soil becomes easily washable. This problem typically exists in mountain areas.

Materials used for fire-fighting or possibly applied fire retardants, foams can penetrate into the soil and change the original balancing chemical processes in it, this way causes acidification or alkalization and changes the soil's chemical composition. These features of fire-extinguishing materials were not investigated, because in the development phase their primary use was not planned in a natural environment. We do not know all the environmental impacts of these chemicals in details, although they are called "chemically natural", they will change natural chemical composition ratios in the soil. For example, artificial acidification can mobilize heavy metal salts in underground water, which were insoluble in natural circumstances before. Thus heavy metals can be incorporated into the plants and get into the food chains.

Atmosphere

A large amount of organic micro particles in the atmosphere emanating from incomplete burning can pollute the air. During forest fires, huge quantities of carbon dioxide (CO_2) go into the atmosphere aggravating the growing tendencies of the greenhouse effect accelerating global warming. [25] Because of forest fires, territories of woodlands and an amount of trees reduce together their photosynthetic performance and oxygen production, making the situation even worse. [26] Due to incomplete burning carbon monoxide (CO) also goes into the atmosphere causing serious health risks to animals and fire-fighters.

With the burning of vegetation additional toxic products of combustion are formed and enter the atmosphere in a large amount. Such chemicals are the different volatile oils, benzene and its derivatives that come out during burning and decomposition of wooden materials. As the burning is incomplete, a lot of remaining organic micro particles in the air also pollute the atmosphere. These micro particles form during the partial breakdown of organic materials. These air pollutants are dangerous and harmful not only at the site of the forest fire and its vicinity, but can be transported with the air movements generated by the fire (mentioned before) to longer distances and higher altitudes. Reaching some kilometres of altitude these chemicals can be transmitted 50–100 kilometres and spread pollution into distant territories. [5]

Water

Forest fires have direct and indirect pollution effects on waters due to the harmful chemicals formed by fires first going into the atmosphere later to the waters by precipitation or sedimentation. Ash, scale and small plant pieces can cause direct surface pollution in nearby waters. Indirectly, the pollution can spread longer distances by the wind polluting distant waters. [27] [28]

Water used for fire-fighting can wash other fire extinguishing chemicals into the neighbouring surface waters, polluting rivers and lakes in the vicinity. Those chemicals that are neutral in soil and only change the chemical composition ratio but are otherwise inactive, can be activated in water by a series of chemical reactions, causing dangerous pollution on much larger territories e.g. alongside a river. These pollutants can endanger or even exterminate water ecosystems. Due to suddenly spreading, large amounts of water used in fire-fighting (especially from air), water balance of the territory collapses, biological balance of natural surface and underground waters tumbles down, animals and vegetation rarify due to rapid modification of living conditions, in the worst case life perishes from the area.

Beneficial Environmental Effects of Forest Fires

Surprisingly, forest fires have some beneficial effects on the environment and to the development of forest ecosystems. It must be emphasized that these are only minor benefits, they exist only from a certain point of view and cannot be compared with the serious negative consequences mentioned before.

Such a benefit is, for example, that the life cycle of some plant species needs repetitive forest fires. Fir-cones of some pine-trees of North America and Europe open only in extreme heat caused by the fire and spread their seeds only in that case. These pine species have strong, thick barks efficiently resisting the fire so forest fires are integral parts of their reproduction process.

Another interesting fact is that frequent forest fires are parts of the reproduction process of some animals and insects also. Larviforms of some insects under the barks of trees can be born only in case of a fire; otherwise they are waiting in pupation form for years.

After a forest fire there is a chance to force back unwanted plant species using conscious methods of forestry.

Another beneficial consequence of forest fires is that burned remnants of vegetation remain on site. Partly degraded organic materials enter the food chain for later utilization as ingredients of rejuvenated vegetation. This way organic materials remain in the recycling process. So only the bigger parts of trees must be transported from the site, small pieces must remain for further utilization as biomass for nature's benefit.

Results

We described effects and consequences of forest fires to forest ecosystems and environmental elements in our paper. It was ascertainable that ruined vegetation and rarefied animal species will cause a collapse in the micro environmental balance and in the food chain. Fire will block and set back regeneration processes. The balancing, life giving and biotope protecting role of the forest will disappear, losses will be serious because of the devastation of biotopes. It is obvious, that harm and negative effects of forest fires will be similar to the whole environment in a larger scale.

We managed to find some beneficial consequences of forest fires also, but they are negligible compared to environmental harm.

We found direct correlation between meteorological extremities being stronger in the last 10 years, decreasing amount of precipitation, higher average temperatures and winters without snowfalls and the increased amount of forest fires in Hungary and within the EU. 80–90% of these fires are caused by human activities, a smaller number is caused by extreme weather phenomena, mainly by lightning. Similarly to other forest protection problems prevention would be the cheapest, most effective solution in case of forest fires, but in parallel with this, we should be well prepared also for efficient fire-fighting and proper handling of caused environmental damages.

In our opinion most of the consequences of forest fires will be revealed only after a longer period of time, and in many cases burned territories can only partly be regenerated or damage could become permanent.

Everyone knows that we need forests in the future, so we described ecological and other damage caused by forest fires. Protection of our forests has a paramount importance, so we must act quickly and effectively to defend them, especially against those want to harm them.

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Single Photon Communication with Avalanche Diodes and the General Basics of Photon Counting

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Single photon communication (SPC) already exists in several applications in laboratory and even outdoor conditions. In the field of quantum cryptography SPC experiments are part of military applications too. There are several methods to detect every single impacting photon in such an experiment. Mostly photomultiplier tubes (PMT) are used. In some cases single photon avalanche diodes (SPAD) are more suitable for photon detection. Both the SPADs and PMTs have advantages and disadvantages. Usually PMTs have much larger detection areas than SPADs, but most of the PMTs detection efficiency peaks at 400 nm wavelength compared to the SPADs, where it peaks at 600–700 nm wavelength. For long distance laser measurements the higher wavelength is more suitable due to the Rayleigh scattering, but the detection hole of SPAD is very tight, which is why it is really hard to target the laser punctually without an optical gyroscope.

Keywords: *Avalanche diode, single photon communication, photomultiplier tube, dead time, noise, Photon Detection Efficiency (PDE)*

Introduction

In general, light detection is possible by the measurement of electrical signals induced by the absorption of the certain light. Photonic communication is based on the modulation of light coming into a detector. There are many ways to modulate light for communication purposes. Meanwhile the single photon communication opportunities open many ways for the safety processes in the field of laser communication experiments. It was demonstrated and published previously that single photon communication is possible in outdoor conditions even over very large distances. [1] [6] Photon counting is possible with the help of a PMT and a photon counter such as the SR400 in Second Harmonic Generation experiments which was already demonstrated in laboratory conditions. [2] The other possible way is to use an optical delay system with an impulse generator and a wavelength doubled laser for PMTs or a red laser for SPADs. Originally the optical delay system was used to develop the antibunching photon. [3] In our case the current detector system is mainly based on the APDs and SPADs instead of PMTs. The use of SPAD based devices has already proved to be remarkably advantageous in a few applications. [23]

It was found from the measurement of the tracking time of pulses and the number of pulses observed per unit time that the number of photoelectrons considered as probability are variable. This can be described by mathematical statistics and the means of probability

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calculations. Electrical impulses received during the detection – a seemingly obvious assumption – is matched to the individual photons. Comparing this with the intensity of classic light, it can be concluded that in a specific location *(r)* and on a certain *dA* surface under unit time a photon detection probability *p (r)* is proportional to the intensity *I (r)* of light (in the classical sense):

$$P(r) \times dA \approx I(r) \times dA \quad (1)$$

The detection of single electrons from the viewpoint of experimental physics is a technical question, which needs to be handled correctly (the coincidence multi-photonic, multi-electronic pulses, dead time, noise, etc.). [5]

Digital Signal Processing Methods, Photon Counting and the Features of Photon Counter Detectors

The pulse given by the multiplication of a single photoelectron can be handled as digital sign. However, if it is expected to be handled in the usual digital device system, it will not be fulfilled yet, unfortunately. There are several reasons why it will not work:

1. The amplitude of the pulses are not the same.
2. The width of the pulses is influenced by many parameters.
3. The dead time, the maximum repetition frequency can also be taken into account.
4. For the examination of the temporal behavior it has to be standardized that when shall be considered a real photon to be "arrived".

The parameters of the two basic types of photon counting detector (APD and the PMT) are different: If we talk about the amplitude at PMT, then we have to realize that the noise and distribution for each photoelectron overlap each other, but only with a partially selectable amplitude discriminator (with the exclusion of very small amplitude – but prolific – noise pulses).

At APDs in Geiger mode (avalanche range) the noise and the photoelectron generate a pulse form. Here it is not possible to select.

About pulse width, it must be pointed out that a PMT works with 50 Ohm load in order to avoid reflections on the cable. Those pulses are dynode capacity dependent which are 1–2 ns width at half maximum.

At APDs there is a 5–10 ns signal falloff after 2 ns upraising. [5]

In Figure 1 the amplitude distribution of the PMT pulses can be seen.

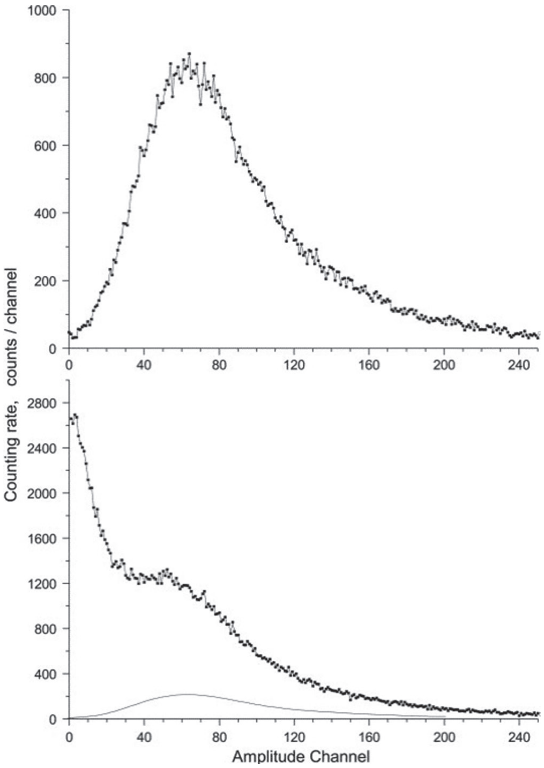


Figure 1. Amplitude distribution of the PMT pulses. (At the bottom with low noise, at the top the single electron distribution given by the subtraction of noise.) [5]

In Figure 2 the oscilloscope view of pulses of avalanche photodiode matrix (M-APD) can be seen. At the bottom the dark noise pulses, at the top the photoelectric pulses can be seen, separable from the 1, 2, 3, … pixel simultaneous sounds evoked impulses.

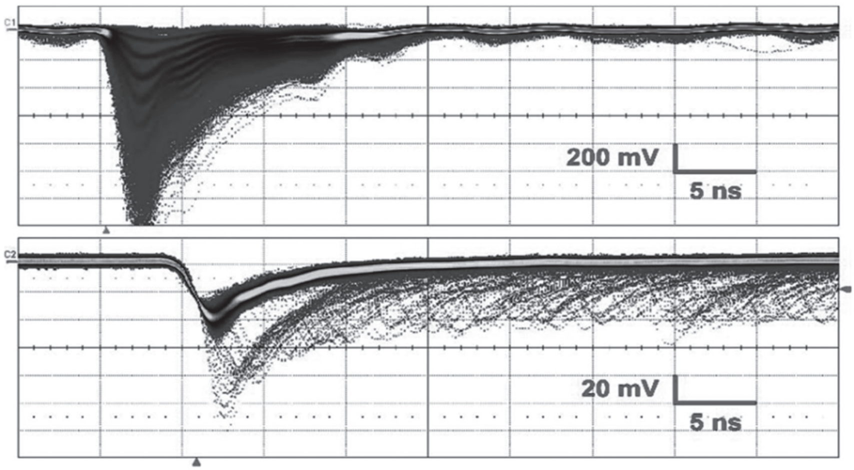


Figure 2. Oscilloscope view of pulses of avalanche photodiode matrix (M-APD). [5]

The parameters of the two detectors (PMT and Avalanche photodiodes (APDs) are different. In terms of amplitude of APD we cannot select in Geiger mode (avalanche range) where the noise and the photoelectron generates a pulse form. In terms of amplitude of PMT, the noise and the distribution belonging to the individual photoelectrons overlap each other, but the amplitude is partially selectable with the help of a discriminator. In this case the low amplitude, but prolific noise pulses must be excluded.

To increase the maximum count rate of a PMT based SPC system it is practical to utilize multiple discriminators. [20] PMTs of different designs and operation principles have been introduced already based on vacuum-tube technology. Those classes of PMTs exhibit narrower height distributions than those of metal-dynode PMTs. [21]

The avalanche photodiodes are very fast acting tools (1–2 ns), and these are also suitable for the registration of photoelectrons raised by individual photons. It has a proportional range too depending on the high voltage, but it is mostly used in photon counting (Geiger-Müller) mode. That means that the formation of one electron-hole pair results in a complete short-circuit. Similarly to the working of the ionization detector, it needs time for the recovery of pre-voltage (dead time). This limits the maximum measurement frequency. It has been already recorded that at a certain wavelength range with this tool the quantum efficiency reached above 90% as well. [5] Figure 3 shows the APD pulses relative to the time sliding of light pulse and the full width at half maximum of the scatter is 210 ps.

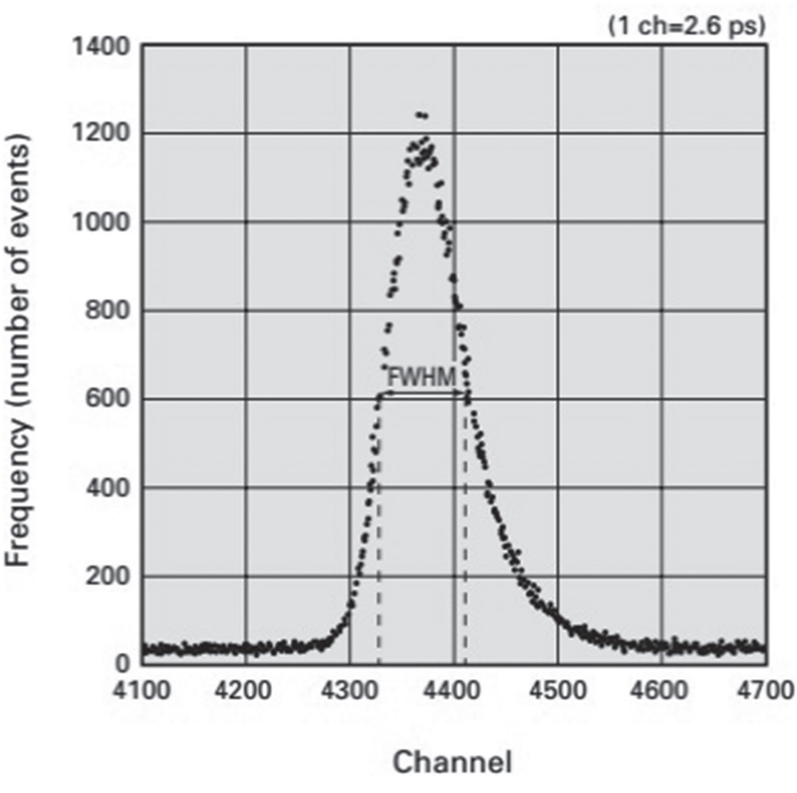
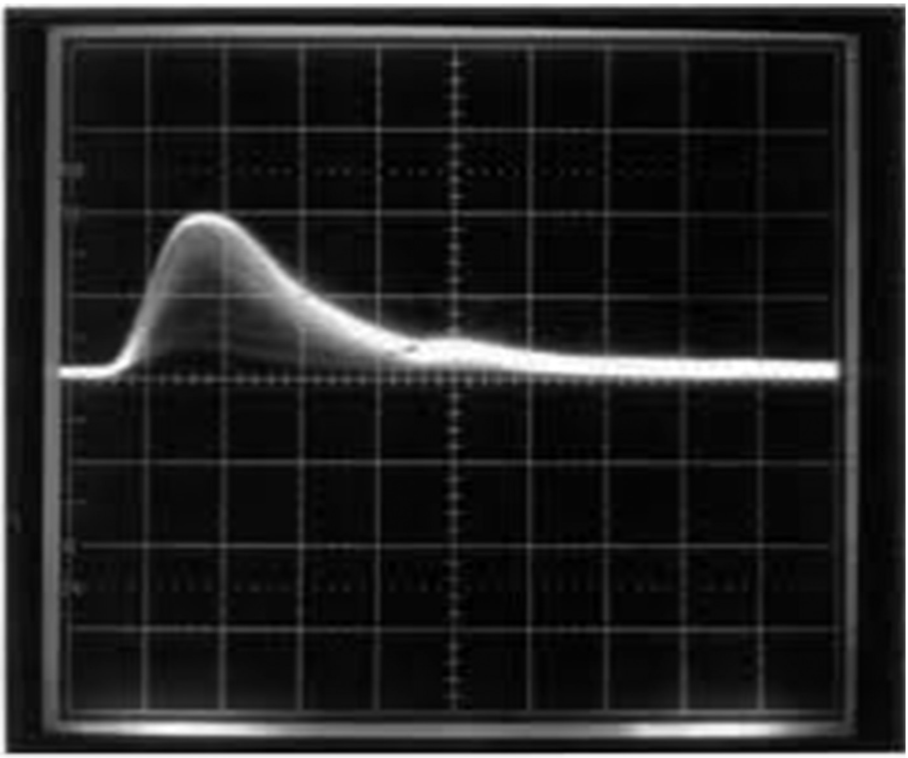


Figure 3. Avalanche photodiode (APD) pulses relative to the time sliding of light pulse (jitter), the full width at half maximum of the scatter. [5]

The principles of time correlated SPC is to detect less than one photon many times repeatedly per cycle. One of the biggest advantages of single photon counting is that it can be used in a really wide range of light intensity:

1. The upper limit is given by the pulse width or dead time (approximately 190–200 MHz).
2. The lower limit is namely the noise fluctuation (approximately 20 pulses/s).

The quotient of these two limits is called dynamic range: D = Imax/Inoise, which is given by either logarithmic or exponential – performance being 10^1 = 20 dB – unit form. In our case the performance is typically 10^7 = 140 dB. Another similar dynamic analog detector does not exist (the typical value is three orders of magnitude). [5] Picture 1 shows the amplitude fluctuation and the distribution function of a single photoelectron signal.



Picture 1. The amplitude fluctuation and the distribution function of a photoelectron signal. [5]

The basics of photon counting has been discussed, [1] [2] but here it is also important to understand the basics of gated photon counting to get a more intense introduction to the photonic communication procedure. This will help us to understand the basics of avalanche diodes.

Gated Photon Counting

To digitally process the signal of the photon counter detectors, they are needed to bring them to the signal level of the usual logic circuits. Typically, this means the level of integrated circuit components made by Complementary Metal-Oxide Semiconductor (CMOS) technique: in the family of +5 Vs the voltage signal ranging is between 0 and +1.5 V at the Low level range, and it can be between 3.5 + ... + 5V at the High level range. It shall be chargeable, although in the older TTL family the consumption of one input was only 40 µA. The CMOS circuits may be perceived more as a capacitive load, so it is only to be expected at high frequencies. To count many photons, short pulses (1–2 ns) should be juggled from our detector, and this is already showing that the wave phenomena will spread in the cables between the devices. If it does not meet with the purely resistive impedance in accordance with its wave impedance, then it will be reflected. For this reason, the detector usually works at 50 Ohm resistor (as a power generator), and the electronic load is not significant. For this reason, the detector usually works for 50 Ohm resistor (as a power generator), and the electronic load is not significant. The problem is that the detector can emit only 10–100 mV amplitude pulses. In order to reach the standard level of these logic circuits, it needs to be reinforced, or with a help of a comparator transform the signals to rectangular shape signals. The gain is not really feasible, as the amplitude (PMT) often shows an order of magnitude deviation. If we want to count only the "photons", a so called fast comparator is used, pulses above the set level generate a quick uprising, the required 5V amplitude square signal. The comparator is often referred to as a discriminator. In fact, by an adequate setting of comparison threshold the small amplitude noise pulses can be ruled out (discriminate). Often upper level discriminators are also used, since the pulses induced by cosmic rays are much larger than the single photon signals. This type is called window discriminator. The pulse width is influenced by two conflicting considerations:

1. The processing electronics – counter – speed, that is what minimum pulse width react to (the older, slower devices meant large capacitive load, only adequately wide pulse was able to fill the capacitor of the input stage).

2. If we have a modern counter, then the shorter the output pulses are, the less dead time is needed to count, that we can measure higher intensity more frequently. The 200 MHz counters are frequent, and that is why the photocurrent is needed to be converted to less than 5ns pulse.

3. If we use longer dead-time APDs, we do not need an extremely fast counter, because the detector would not be able to indicate frequently (maximum 10 MHz). [5]

In Figure 4 different types of photon counting techniques can be seen. From the view of photon counting the typical optical spectroscopic measurements that require time resolution fall into three main categories:

There can be less than 1 photon per cycle in the periodic measurement cycles. It needs bigger time resolution than what the detector has (to all the time windows impact only one photon once in 10–100 cycles).

There are two photons in one cycle and the time resolution has a greater scale than the temporal resolution of the detector (one cycle of time window contains a lot of photos).

There are many photons in one cycle and the temporal position of each photon can be fixed by adjusting the definition of the detector (in one cycle to a time window impacts only one photon). [5]

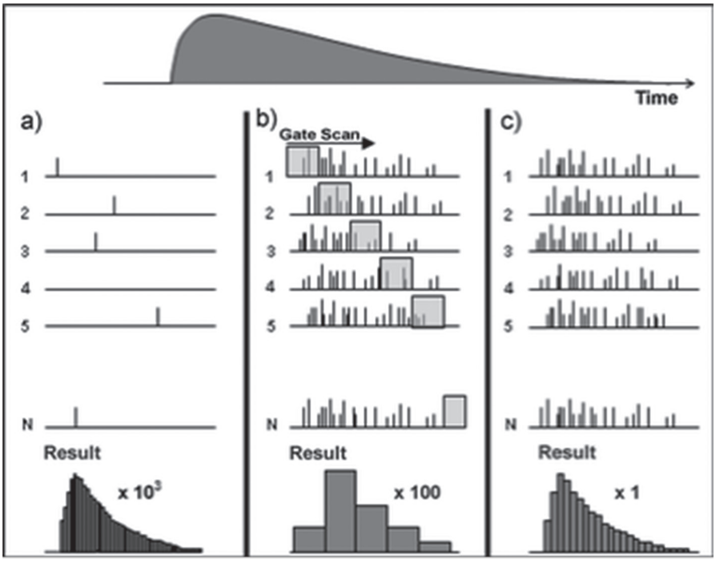


Figure 4. Various techniques for single photon counting. [5]

The name of *Version A.* Time Correlated Single Photon Counting. It outlines the case when a very fast process takes place after the short excitation pulse. It needs to have better time resolution than most of the detectors have (1–2 ns). This can be achieved by a certain theoretical agreement that explains that the detection probability of classical light intensity and the certain photon in time unit – proportional to each other – by definition.

So if the detectors are unsuitable for breaking down the simultaneously arriving photons on the chosen time scale, then it must be achieved that there should be only one photon at the time of a measurement cycle. The temporal distance of the detection and appearance of photon will be the parameter (measured from the short excitation impulse), which will be measured. The processing system uses an appropriate number of time channels. All measurements give a time frame, it will be the time channel number. All contents corresponding to the cycle time channel measurement results will increase the value by 1. After many measurement cycles (10^5–10^6) the probability density function of the photons temporal distribution emerges. The figure of this is equal to the time function, which could have been measured as analog signal by a detector with proper resolution. It is obligatory to make very low intensity signal response for the measurement. It can be achieved by intentional depletion. Preferably it can be achieved by the weakening of excitation, but the response signal can be also weakened with the gap narrowing of the spectral resolution, or with the use of gray filter. Since the detection of photons is a random process, we must investigate what are the chances of arrival not only for one photon in a measurement cycle to the detector, but two or more. Specifically, we must determine the average intensity of what comes to the detector which in the case of the simultaneous presence of a sufficient number of photons have low probability. [5]

Version B.: gated integration. In this version the gate width is much longer than the time dissolution of the detector and this steps forward in time with a gate width relative to the exciting pulse in every cycle. For this we need only one single-channel counter, performing data processing unit (PC) is organizing the scanning time.

Version C. is supposed to be a multi-channel counter (PC with a digital I/O/timer/counter card), where every measurement cycle are the same. The measurement must go on until there will be enough counts for the statistical processing in the individual channels.

Principles of SPADs

SPAD detectors so far reported can be divided in two groups, according to the depletion layer of the p–n junction, which can be thin, typically 1 µm, [10] [11] or thick, from 20 µm to 150 µm. [7] [8] [9] [12] [13] [14] However the required active area at the largest fast SPADs have a diameter with even 200 µm. The main features of thin-junction SPADs are: fairly good quantum efficiency in the visible range, about 45% at 500 nm which declines to 32% at 630 nm and to 15% at 730 nm, and is still useful in the near infrared (NIR), being about 10% at 830 nm and a few 0.1% at 1064 nm; small active area, with diameter from 20 µm to 100 µm; breakdown voltage *V*B of 20V–50V. Instead thick-junction silicon SPADs have: breakdown voltage *V*B of 200V–500V; fairly wide active area, with diameter from 100 µm to 500 µm; quantum efficiency that is very high in the visible region, remarkably better than 50% over the range from 540 nm to 850 nm wavelength, and declines in the NIR, but is still about 3% at 1064 nm. [4]

Figure 5 shows the cross-section of a thick SPAD. [19] The active area is defined by an n++ phosphorous diffusion both by increasing the p− quasi-intrinsic substrate concentration with a p diffusion and by fabricating low-doped n− phosphorous guard rings at the junction edges. The wafer is then flipped and back etched down to 30–40 µm from the active area. A p++ boron diffusion is then created to provide a low resistance path for the avalanche current and a good ohmic contact with the anode metal deposition. The backside contact is the cathode. This structure is designed to deplete all the 30–40 µm thickness, thus providing both a thick depletion region and a high electric field all over the space-charge zone. [4]

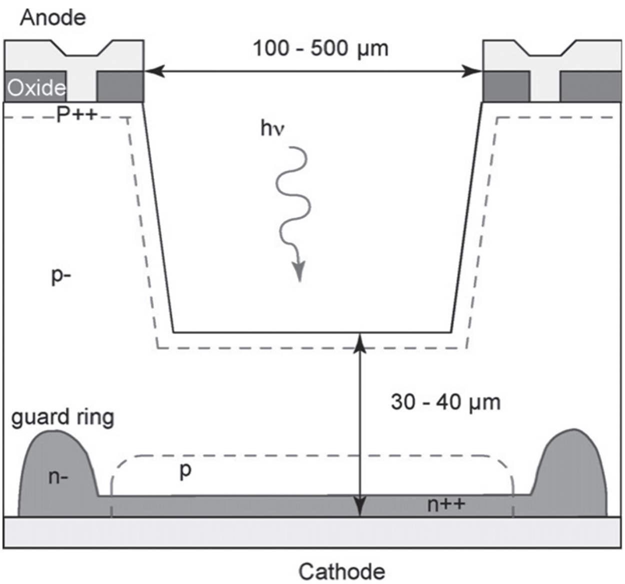


Figure 5. Cross-section of a thick SPAD. [4]

Difference between APDs and SPADs

The term SPAD defines a specifically designed category of APDs working with a reverse bias well above the breakdown voltage, in a way that completely differs from normal APDs, operated below the breakdown level. The reverse biased p-i-n diodes are common silicon photodetectors essentially. That means the incident light generates electron–hole pairs in the depletion region contributing to the reverse current. The increase of the diode current is proportional to the incident light intensity. In order to have an internal gain between absorbed photons and output carriers, many APDs were proposed and developed. [15] They operate just near, but below breakdown which means that photo-generated carriers can produce other carriers via impact ionization process (Figure 6 on the left). However such process is not diverging and the result is an amplified response compared to normal photodetectors. [4]

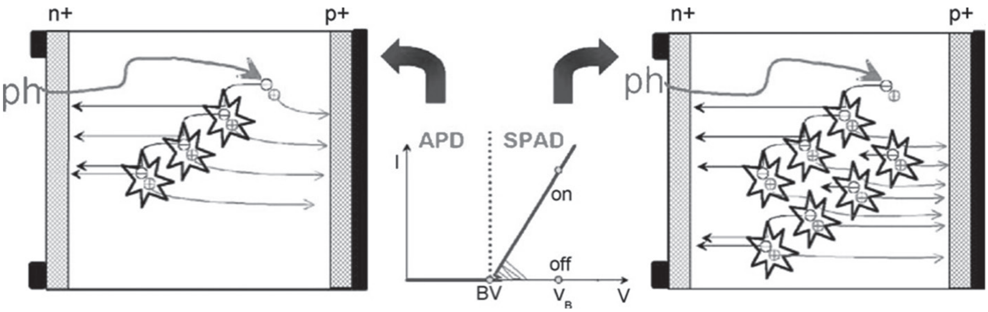


Figure 6. APDs are biased just below VB in order to have a non-diverging multiplication process (linear multiplication) of the photo-generated carriers (left side).
Instead SPADs are biased well above VB so that one photo-generated carrier can trigger a diverging avalanche multiplication process, leading to a macroscopic detectable output current (right side). [4]

Because the avalanche process has high statistical fluctuations (leading to excess noise [18]), APDs are used with relatively low gain (a few hundred at best), and therefore the detection of single-photons is possible just in few cases, with severe limitations and low detection efficiency. Single-photon avalanche diodes (SPADs) exploit avalanche multiplication in a different way. At a bias higher than the breakdown voltage, they work in Geiger-mode (Figure 6 on the right): a photo-generated carrier in the depletion region can trigger a diverging avalanche multiplication of carriers by impact ionization. [15] [17] Impact ionization involves both positive and negative carriers, with an inherent positive feedback effect that, if the electric field is high enough, making the carrier multiplication self-sustaining. This is often referred to as a divergence to infinity of the multiplication factor; in fact, the current is finite because of a space-charge effect, [15] which produces a finite internal resistance of the device that lowers the voltage drop across the junction. In normal APDs, turning off the incident light will immediately terminate the multiplication. Instead, an SPAD does not turn off by itself when triggered, – therefore the photo-diode must be reset, i.e. the avalanche process must be quenched –, in order to make the detection of a subsequent photon possible. [4]

Figure 7 shows an example of the overall photon-detection efficiency as a function of the excess bias for thin and thick SPADs and Figure 8 shows the photon detection efficiency (PDE) of thick, thin and Red-Enhanced SPADs.

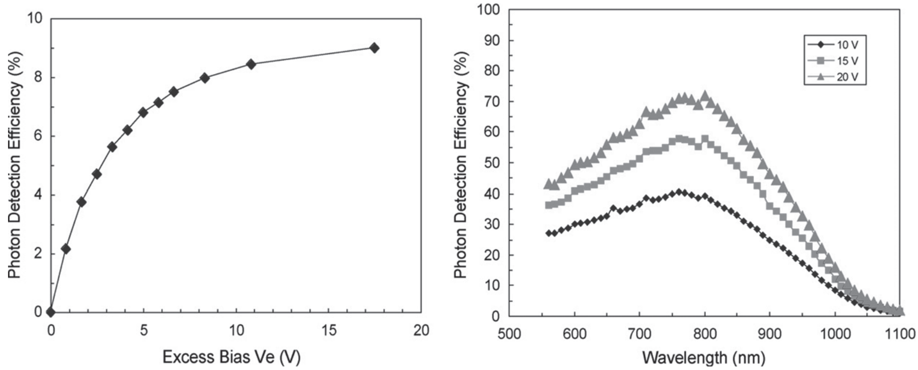


Figure 7. Photon-detection efficiency at different excess bias for a thin SPAD (W = 1 µm) at λ = 850 nm (left) and for a thick SPAD (W=25 µm) (right). [4] [16]

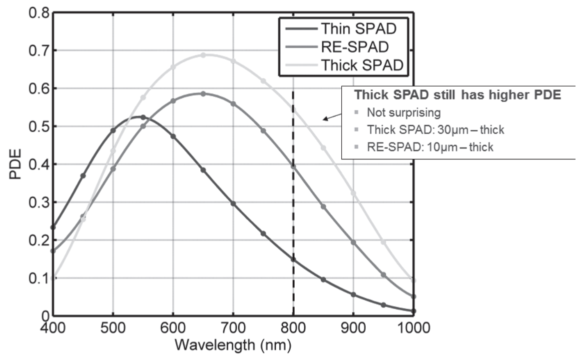


Figure 8. PDE of thick, thin and Red-Enhanced SPADs. [22]

Conclusions

In this paper the basics of photon counting and the basic principles of single photon avalanche diodes and avalanche photo diodes have been discussed. APD and SPAD characteristics and physics have been also discussed and analyzed. As we have seen there are various techniques for single photon counting, where all methods have advantages, but technological difficulties too. The question of "which one we want to use?" depends on what we want to communicate and of course also depends on the technological instruments we have. For outdoor measurements during daylight it is extremely difficult to use APDs and SPADs for single photon communication due to the very high sensitivity of these detectors. Even in a very dark night we can have difficulties due to the light of the stars. To make outdoor measurements with these tools one of the acceptable steps is to use high quality filters on the front of detectors.

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10th Anniversary of the Parallel Flood Control on the Danube and Tisza Rivers in Hungary in 2006

Árpád MUHORAY[1]

The paper wants to present the work done during the management of major floods and inland waters in Hungary ten years ago, in the year of 2006, to safeguard the population, and the measures taken during the protection activities. It was very important for everybody who had responsibility for the operational control of the response to disasters and emergencies in Hungary (floods, inland waters, extreme weather conditions, to simply say: the range of natural and man-made disasters), especially for the population living along the Danube and Tisza Rivers.
Keywords: *river, flood control, inland water, geographical features, parallel flooding, inundations, disaster management, water management experts, dump, dyke, sandbag*

The Precedence of Floods and Inland Waters in Hungary were as Follows

The purpose of the paper is to present an overview on the efforts made during parallel flood control on the rivers Danube and Tisza in 2006, from ten years' perspective. [1] At the beginning, it is worth clarifying what the specialist literature means by the concepts of flood and flood control.

Flood: the temporary covering by water of land not normally covered by water. [2]

Flood control: preparing for and organizing protection against floods and any other activities related to protection carried out after the flood wave recedes. [3]

Due to Hungary's relief and drainage features, frequent inundations endangered large and high-value areas. The catchment areas of Hungary's rivers are in the high mountains of the Alps and Carpathians mainly outside the territory of our country.

According to statistics, minor or moderate flooding can be expected every 2–3 years, major flooding every 5–6 years and extreme flooding every 10–12 years. The duration of major flood waves on the upper sections is 5–10 days, while on the middle to lower sections it can be as long as 50–120 days. Based on the extent of flood plains, Hungary "boasts" the highest level of flood vulnerability in Europe.

Due to the climate and geographical features of Hungary and the surrounding regions, flood effects may occur on any of the rivers, anytime of the year.

The 21,000 square kilometers flood area in the valleys of the Danube and Tisza Rivers is protected by 4220 kilometers long flood control embankments. One third of the country's arable land is found here. One quarter of Hungary's population lives in the 700 settlements of the flood area.

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Due to the geographical features of Hungary, mountain reservoirs are not available to withhold water, as they are located outside the country. Our rivers on the Great Plain run with a slight descent, therefore they had to undergo regulation such as cutting through the bends and building dams and dykes.

One of the most common methods of flood control is to prevent spreading of water by establishing flood control embankments. They are the primary ways to protect national economic values. The 4200 kilometers long flood control embankments mentioned earlier also belong to this category, so they bear high significance.

Natural disasters, including river and groundwater flooding belong to natural events. If we take a look at their history, it is clear that they have been part of humanity's history since ancient times and the future is expected to be no different. Moreover, their impacts might be even more damaging and destructive as a result of global climate change.

Floods have played a large part in society, the extent of the part depending on the extent they endanger or destroy human lives, health, material and cultural goods and affect agricultural activities.

Effective flood control can prevent significant losses. For instance, in 2001 in the region of Bereg, the dam on the River Tisza collapsed by the settlement of Tarpa due to the extreme flood. The losses suffered were worth over 100 billion HUF.

In order to protect the population, settlements, agricultural and industrial establishments, a coherent and effective flood control system was called for against the destructive effects of floods.

In line with our national legislation and the professional requirements, our methods for flood control can be divided into two main groups: a) structures, b) non-structures.

The tasks of flood control are laid down in paragraph 16 of The Water Management Act [4] as follows: protection against the destructive effects of floods, including building, developing and maintaining embankments is the responsibility of the state, local governments and those interested in preventing and mitigating losses. The Visegrád Four countries are members of the EU. In the interest of its members, EU has reviewed the situation of flood control and issued the Water Framework Directive (2000/60/EC), which sets the framework for the community action in the field of water policy. The Directive was adopted in Hungary in 2003–2004. Therefore, Hungary's flood control is in line with EU recommendations.

Inland Waters

The considerable amount of precipitation since the autumn of 2005 has raised the amount of water resources in the ground by 95 percent. The large amount of snow and the continuous rainfalls greatly contributed to the inland inundations in large parts of the country.

Due to the continuous worsening of the inland water situation, the size of the flooded areas grew to 224 hectares and the number of evacuees exceeded 220 persons, the number of vulnerable buildings was 1100 and the number of vulnerable population reached 3200 persons. (As a comparison, in 2000, 2860 persons, in 2001, 12,886 persons and in 2002, 2021 persons were evacuated. In 1999, the inundated areas reached 380,000 hectares in Hungary)

The affected ministries and national authorities, furthermore the county disaster management directorates prepared themselves for the response to floods and inland waters. The notification, call-in and activation plans at the counties, the aggregated evacuation and reception plans, the emergency supplies accommodation possibilities, the aggregated emergency plans and the databases of equipment used during flood and inland water response were updated.

The majority of the directorates created the possibility of accommodating the population from the vulnerable areas at the reception settlements in a very short time by updating the availability of the designated facilities.

Besides the flood and inland Water management efforts, another problem was that due to high ground water, in several settlements a ban on funerals had to be ordered.

The flood control activities were carried out under the direction of water management experts, by the county disaster management directorates and the municipalities conjointly, using the material stocks available. The number of responders was 1200–1500 persons daily, in average.

Parallel with the inland water control, flood management activities had to be started as well. This is unusual because in general the situation is reverse.

Flood

The parallel flooding of the Danube and Tisza Rivers is very rare, it only happens every 50–60 years. Hungary's two main rivers, during the spring flood in 2006, broke the highest water level records in the past 100 years, simultaneously endangering the population and the traffic in the flooded areas.

On 30th March assets and work force had to be gradually regrouped from the inland control activities to the Danube River in North Western Hungary to carry out flood control works. Exhausting flood control efforts were made at Győr and in the region of the Danube Bend and Budapest. Due to the sudden rise of water level of the Tisza River, flood control activities had to be started in the upper section of the river. The most critical situation evolved in the regions of Tokaj and Szolnok.

A declaration of emergency was made at 1500 hours on 3rd April (by Government Decree 76/2006. (IV. 3.) on the Komárom-Tass section of the Danube River, and on the section of the Ipoly River between Ipolytölgyes and its mouth. The revoking of the emergency took place at 1500 hours on April by Government Decree 85/2006. (IV. 10.).

A significant problem was caused by the fact that the flood wave on the Danube was caught up by the one on the Tisza River, and the water streams, which had slowed down, caused high water levels for several weeks in Hungary. Therefore, exhausting efforts were made at the same time along both major rivers.

The declaration of flood emergency for the Tisza River was made at 1300 hours on 14th April (by Governmental Decree 87/2006. (IV. 14.), on the Tisza River from Kisköre to the state border, on the entire Hungarian section, of Maros River, on the Hármas-Körös River from Mezőtúr to its mouth, and on the mouth section of the Zagyva River.

At 1700 hours, on 18th April on both banks of the Hármas-Körös River, including the section to the mouth of the mouth of Kettős-Körös River, the emergency was extended.

Besides the activity of the central unit of the flood control, the National Technical Direction Staff, the Operational Staff and Emergency Center of the Governmental Coordination Committee, operating at the headquarters of National Directorate General for Disaster Management (NDGDM), continuously carried out flood and inland water management tasks.

The county protection committees periodically assessed the situation and took measures for implementing the most necessary tasks.

Protection committees, county disaster management directorates, their civil protection branches and mayors paid much attention to public information and the code of conduct even at the onset of emergency situations. [5: 113]

Flood protection preparedness was valid on approximately 2200 kilometers, the number of participants in the flood control efforts was 20,000–25,000 persons daily, during which approximately 10 million sandbags were used to reinforce the protection structures.

Due to the slip and cracks on the dykes in the region of Szelevény, on the Hármas-Körös River, in order to guarantee the safety of population of Tiszasas and Csépa villages, the Chairman of the Protection Committee of Jász-Nagykun-Szolnok County, by issuing his decree 7/2006. (IV. 23.) ordered full evacuation in Szelevény, and partial evacuation from the areas in Csépa, and Tiszasas lying lower than +86 meters measured from the level of Baltic See.

During the flood and inland water protection activities 2500 persons were evacuated. Out of this number 280 persons had to be evacuated because of the flood wave on the Danube. Out of this number 230 persons were evacuated because of the inland waters.

The number of settlements performing flood and inland flood control activities has reached 350: a) 200 flood control, b) 150 inland water control activities. Extraordinary flood control preparedness was ordered in 79 settlements.

Under the guidance of water management experts, besides the population of affected settlements, manual worker squads from civil protection organizations, disaster management and fire service personnel, and soldiers from the Hungarian Defence Forces participated with their special equipment. Even if forces and equipment were sufficient during the management today it could be more professional by using new technologies. [6]

The flood wave on the Danube River left Hungary on 24th April and at the same time reconstruction began.

Lessons Learnt during Inland Water and Flood Control Activities

In Hungary, the availability of dykes is satisfactory. It meets the requirements of highest expected water levels. However, the protection structures are incapable of holding high water levels for a longer duration of time (2–3 weeks). Therefore, the technical conditions of the dykes have to be regularly controlled and the various flood effects necessitate the continuous attention of all the participants.

The successful involvement of Hungarian Defense Forces, and civil protection organization was the guarantee of the well organized and disciplined implementation of tasks. They can be easily mobilised and have rearrangeable equipment (amphibious, aviation and pontoon). Therefore, their personnel can be deployed even in such places where other, non-military forces cannot.

The use of civil protection organizations had a very awkward start, since the Public Labor Program, announced by the Government, covered the same people as designated duties. We have overcome this problem, and at Szolnok and Szeged, the civil protection organizations helped the flood control efforts with 7000 persons.

Disaster tourism meant a great problem for the experts directing the flood protection activities in large cities (Budapest, Szeged and Szolnok). This kind of problem was also mentioned at the floods of Borsod County, which happened in 2010. [7] Other restrictive measures were the limitation of the use of airspace, navigation ban, speed limits for rail and public transport.

Positive sides were:

- there is a well-functioning emergency management system (line ministries, the bodies of Governmental Coordination Committee, protection committees of counties, experts with experience from the previous exercises in emergency management);
- availability of initial protection stocks and equipment at the most vulnerable settlements, thus making the immediate response possible;
- the Government responded in due time and declared emergency and allocated the necessary resources to manage the floods;
- the protection was directed by experienced water management experts, the regrouping went on in an organized way between the Danube and the Tisza Rivers, the same applied to National Directorate General for Disaster Management with the civil protection and fire service personnel;
- the reinforcement of the protection structures slipped because of the continuous water load in a conjoint way (civil protection, fire, Hungarian Defense Forces, water management experts, voluntary non-governmental organizations [NGO's], etc.) was possible because of the well-organized local direction;
- the evacuation of settlements vulnerable to inundation (population, livestock, tangibles, hazardous wastes, etc.) was accomplished based on the plans made and continuously updated by disaster management organ;
- the Government made significant efforts to help the people living in the areas stricken by floods and inland waters, request for international assistance was made through European Union Monitoring Information Centre (EU MIC), we received offers from Austria, Romania, Slovenia and Sweden;
- the activity of civil protection experts helping the municipalities greatly contributed to the successful flood control and the coordinated activity of organizations participating in the protection efforts: county disaster management directorates and water management directorates;
- besides managing our own emergencies we were helping the countries of the region (Romania, Serbia and Bulgaria, requested on 25th April). Our helping was very necessary for Serbia, because in the region of Vajdaság a lot of dams of rivers were destroyed from floods.

Status of Cooperation

Early 2006, the floods in Central Eastern Europe directed the attention to the necessity of international cooperation between the different countries.

In order to accomplish a wide range of cooperation it is expedient to attach importance to:

- mutual assistance;
- implementation of joint flood protection projects and tenders;
- establishment of Flood Emergency Response Unit in each country, their use in each other's countries, if necessary;
- elaboration of uniform protection guidelines and statutes;
- establishment of professional contacts with the organizations of foreign countries involved in emergency management;
- building joint monitoring systems;
- harmonization of databases;

- joint training of experts participating in flood protection;
- expansion of cooperation into other fields of disaster management (fire, nuclear emergency management, cross border transportation of hazardous materials, the management of the consequences of major industrial accidents, etc.).

Conclusions

In conclusion, it can be stated that parallel flood control on our two major rivers Danube and Tisza in 2006 was highly effective. State control was successfully conducted, water and disaster management bodies together with other state organizations, voluntary NGOs, local governments and the affected population did their best to protect embankments.

Even at the 10th anniversary, the success of flood control in Hungary is highly remarkable, since floods claimed no human casualties in Hungary. Dams proved to be reliable and they persisted, except for the dam collapse in Tarpa in 2001, and the floods in Borsod in 2010.

Hungary welcomes suggestions from other countries and the lessons learnt during the flood control activities from neighboring countries, the VISEGRAD 4, in order to enhance our own organizational and flood control system.

Based on experience of the past years, the government intends to strengthen prevention, so the National Directorate General for Disaster Management (NDGDM) has recently taken over water management authority tasks related to licensing and supervisoring, [8] while the organizations in charge of actual flood control, that is, the Hungarian General Directorate and the Directorates of Water Management are subordinate to the Ministry of Interior. The Parliament passed the new Disaster Management Act [9] in 2011, coming into force on 1st January, 2012. The newly introduced tasks are intended to ensure an even higher level of protection to the population and material goods in flood situations.

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Industrial Safety Analysis of Accidents Involving Ammonia, with Special Regard to Cold-Storage Facilities II

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Anhydrous ammonia is widely used in industry (chemical industry, refrigeration technology) and it is produced, transported and used in large quantities. From the viewpoint of industrial safety, this material is essential as it is present within the area of almost every branch office of disaster management. It is a statistical fact that the number of major industrial accidents involving ammonia has not declined. The purpose of this paper is to offer a professional summary and resolution for operative professionals and decision-makers on this topic. Therefore, the closely related issues are described together with the possible solutions. This paper is the second part of a series of articles.

Keywords: *ammonia, ammonium hydroxide, chemical reconnaissance, safety planning*

Introduction

The paper attempts to present the whole range of the uses of anhydrous ammonia in cold storage facilities from the viewpoint of industrial safety, from safety planning to emergency responses.

Due to the complexity of the topic, the article was published in two parts. The first one described the physical and chemical hazards of ammonia together with the assessment of safety risks and the impact analysis, whereas the second one deals with safety planning and emergency response.

The Government Decree of Hungary 219/2011. (X. 20.) on the protection against major accidents involving dangerous substances regulates internal safety planning and major incident response planning in companies obliged to do so. It specifies the contents and the structure of the plans, so in line with this regulation, we wish to describe safety planning, the dangers on intervention units and the basic tasks in emergencies (intervention, first responders). [1]

Industrial safety planning – including mitigation, protection of the staff, the civilians and, last but not least, the intervention units, preparedness, prevention and response as well – is the integrated use of natural sciences, geographic information science and legal regulations. This article attempts to provide assistance and to offer a practical assessment of a dangerous

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material from the viewpoint of industrial safety and the related emergency planning procedure. All responsible business leaders have to perform industrial safety planning and this paper attempts to provide help for corporate leaders and disaster management by describing the process of industrial safety planning in dangerous industrial establishments.

Safety Planning and its Contents

According to the Government Decree 219/2011. (X. 20.) on the protection against major accidents involving dangerous substances, [1] establishments using anhydrous ammonia are identified as below tier establishments in Hungary. In this case, the establishment submits a request for a disaster management license to the competent County Directorate for Disaster Management, for which a Major Incident Response Plan (MIRP) is required. The MIRP has to comply with all the requirements for the form and content set out in the Government Decree 219/2011. (X. 20.). [2]

The establishment using anhydrous ammonia collects, systematizes and evaluates data on all its affected plants. Then, in a standard procedure it identifies its dangerous units based on Seveso-III (Directive 2012/18/EU) criteria. [16] In the designated parts of the establishment it analyses in detail and documents the technologies used, so that they are suitable for exploring all the necessary and sufficient conditions for the impacts to extend beyond the area of the establishment. In light of the conditions, it reveals the results, including the scenarios with adverse impacts, which might extend beyond the area of the establishment. With the help of an internationally accepted assessment method, it determines the frequency of occurrence of the given scenarios and in an impact analysis it identifies the consequences of the scenarios in the units dealing with dangerous materials. [1] [2]

In the light of the frequency of the occurrence and their consequences, the establishment carries out its industrial safety assessment.

Being aware of the potential major incidents and their impacts, safety planning is carried out in the form of a MIRP.

Compulsory Content Points of Safety Plans

1. Description of the below-tier establishment and its surroundings [3]

Methodology of the designation and assessment of a vulnerable zone: when specifying the principles and length of the assessment within the Major Incident Response Plan, the requirements set out in Act CXXVIII of 2011, [15] Directive 96/82/EC [17] and Government Decree 219/2011. (X. 20.) [1] are considered decisive.

The description has to include the following items:

- settlement planning in the vicinity of the below-tier establishment;
- the description of the dwelling area;
- a list and description of the facilities frequented by the population;
- natural areas, special natural values;
- utilities that might be affected by hazardous materials incidents;
- traffic and demographic data included in the vulnerability assessment;
- surrounding economic entities;
- hazardous activities of other operators in the vicinity of the below-tier establishment;

- description of the natural environment, meteorology and its impact on the technology;
- geology, hydrogeology and their impact on the technology;
- vulnerability of the natural environment from hazardous materials incidents.

2. Description of the below-tier establishment

General description of the activities of the below-tier establishment:

- the function of the below-tier establishment;
- the number of staff, working hours;
- the number of shifts;
- general statements on the below-tier establishment;
- description of the dangerous plants of the below-tier establishment;
- inventory of the hazardous materials present, identification, classification and quantity of the hazardous materials.

Further information to support hazard identification:

- processes involving dangerous materials and their typical parameters;
- description of the ammonia-based refrigeration system;
- storage of waste and hazardous materials;
- description of the safety and detection system of the technology;
- operational statuses other than the normal one, (temporary) storage of hazardous materials and related activities, decontamination materials at the site. [3]

3. Detailed description of the potential major incidents involving hazardous materials. Visual representation of the technologies

4. Risk assessment of major incidents involving hazardous materials

This chapter has to address the following items:

- data collection and systematization, preliminary analysis;
- inventory of the hazardous materials present;
- identification of the below-tier establishment;
- preliminary analysis based on selection and indication numbers;
- presentation of the technology in the establishment from the viewpoint of safety, determining the accident frequency rate;
- description of the methodology applied, presentation of the ammonia-based refrigeration system and determining the frequency rate of major incidents;
- the frequency analysis of endangering the neighborhood and its impact analysis;
- impact analyses of the specific scenarios;
- impact analysis of environmental pollution;
- domino effect analysis, analysis of external domino effect, analysis of internal domino effect;
- industrial safety assessment, assessment of individual and social risk. [3]

5. Forces and organizations involved in the response to major hazardous materials incidents

Leader of incident response team, incident response team (executive body), on-site resources that can be involved in the rescue, mobilizable team (intervention unit), first aider, reception, personnel working in the vulnerable zone, outside contractors or visitors, off-site resources that can be involved in the rescue, equipment that can be used in the response, infrastructure, utilities, electricity and other energy sources available for the response, backup power supply.

Fire extinguishers, fire water system, command centers in emergency, notification of management in emergency, alerting personnel in emergency, emergency communication devices and systems, evacuation shelters, technical infrastructure aiding control, situation assessment and preparation of decisions, information systems, on-site equipment available for the response.

6. Protection tasks

Major incidents involving hazardous materials, general code of conduct, emergency measures, alarm, immediate response to mitigate damage, escape, evacuation, follow-up activities, investigation, report, reporting obligation.

7. Training and drills

The organization responsible for training, the training program, its schedule, the main content points of the exercises.

8. Safety management system

Organization and personnel, identification and assessment of major incident risks involving hazardous materials, management of the establishment, managing changes, safety planning, internal audit and management review.

9. Organizations involved in planning

Organizations and contractors that are involved in safety planning.

10. Summary

Summarizing the organizations involved in safety planning, the purpose of the plan, the brief description and deadline of the technological modifications needed to achieve the purpose.

An Example for Identifying Individual and Societal Risks

We presented risk assessment in SAVE II[5] environment to determine accident frequency studied in the first part of the paper. SAVE II is able to display the results graphically and also using vector-graphics in MIF (MapInfo Interchange File Format – MIF) format. SAVE II is a disaster management application approved by the Dutch Ministry of Infrastructure and the Environment. SAVE II is an accepted program in most countries of Europe to identify the consequences and assess the risks of incidents in dangerous establishments falling under the scope of the SEVESO directive. Risk Calculation Module of SAVE II is used to perform risk analysis. It is possible to define a model area and the density of its division. The necessary input data cover meteorological information, population information and frequency probability of the incident. A set of risk values is the output, represented as a closed curve in the *xy* plane in the case of an individual risk, while regarding societal risks, it is represented as a smooth curve in the FN[6] plane (FN-curve).

The model area is 1000 meters wide in the east-west direction, and also 1000 meters wide in the north-south direction. The area is divided up into cells of 10 meters by 10 meters. [4]

5 The SAVE II program is intended for individual and societal risks, calculation and to graphically display them. The risk of outflow, evaporation, steam, gas diffusion, fire, heat radiation and pressure, based on the analysis are set out in an explosion.

6 Societal risk can be presented by FN curves, which are plots of the cumulative frequency (F) of various accident scenarios against the number (N) of casualties associated with the modelled incidents.

When performing risk calculations, probit values determined in the first part of the paper are used. The *a*, *b*, *n* are probit values of ammonia are contained in standard E of CPR18.:

substance/effect	**a**	**b**	**n**
NH_3	–15.6	1	2

All major incident scenarios, identified in the "red" zone by HAZOP analysis, were taken into consideration in the risk calculation of the given establishment, as can be seen in Figure 1.

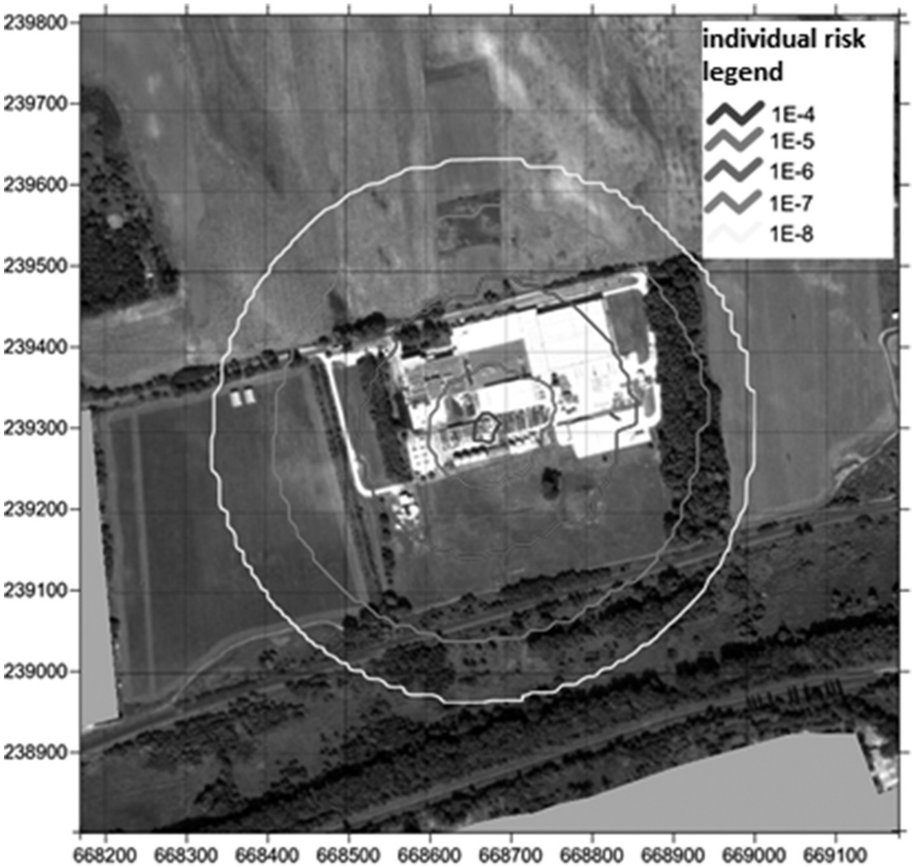

Figure 1. Individual death risk in the establishment under scrutiny represented on a map. [18]

The danger zone with 10^{-6} fatalities/year does not affect residential areas. According to the Governmental Decree 219/2011. (X. 20.), [1] individual risk can be accepted without conditions provided the residential area is in a zone with a lower risk than 10^{-6} fatalities/year resulting from major incidents involving hazardous materials. [5]

Determining Societal Risk

Societal risk is assessed on the basis of Governmental Decree 219/2011. (X. 20.). [1] Upon calculating it, the population of the danger zone as well as people temporarily staying there (at work/school, in shopping malls or entertainment facilities) are taken into account. The result is depicted in an FN-curve.

X-axis of the FN-curve represents the number of deaths (N). The number of deaths is represented on a logarithmic scale, where the lowest value is 1. Y-axis of the FN-curve shows the total frequency of incidents with N or more number of deaths. These values are represented on a logarithmic scale as well, where the lowest value is 10^{-9} incidents/year, as can be seen in Table 1. [6]

Table 1. Societal risk and assessment. [6]

Societal risk	**Assessment**
$F < (10^{-5} \times N^{-2})$ 1/year, where $N >= 1$	Acceptable without conditions
in the range of $F < (10^{-3} \times N^{-2})$ 1/year and $F > (10^{-5} \times N^{-2})$ 1/year, where $N >= 1$	Acceptable with conditions
$F > (10^{-3} \times N^{-2})$ 1/year, where $N >= 1$	Not acceptable

When assessing societal risk, an identical model area to the one described in the calculation of individual risk was used. Risk curves do not affect residential areas or places of assembly. However, they do affect railway line 80A Budapest – Hatvan – Miskolc. Although, there is no exact traffic data available on this line, according to the current railway schedule, altogether 44 trains travel on the affected route every workday. [6]

Risk Directly Affecting Operative Units

Incidents involving hazardous materials pose various types of threats to the quality of human life. Often several risks are present at the same time, which may be the following, as can be seen in Table 2.

Table 2. Typical hazards of ammonia. [7]

(Physical) Effects of an explosion	shockwave and flying debris as well as high temperature
Effects of intoxication	toxic materials may enter the body through inhalation on skin absorption
Effects of suffocation	lack of oxygen because of the smoke or the gas leak
Effects of fire/heat	threats related to the heat and fire are the burning gases, liquids or powders (e.g. liquid gas, oil or carbon powder)
Effects of oxidation	threats related to flammable materials (oxidants), which can result in increased burning and heat

Effects of chemicals	contact with acids and bases can cause damage to the skin, eye or mucosal surfaces
Effects of freezing	frozen liquid spills or high pressure gas leaks may cause frostbite
Effects of infection	body becomes infected
Threats on the environment	risk of water, soil or air pollution

Management of Incidents in Cold-Storage Facilities

The above mentioned physical, chemical and biological risks have to be considered when the intervention is planned. In incidents involving anhydrous ammonia, like in other incidents, the top priority is to rescue the victims. All the other tasks are preceded by it or performed for this purpose. Response plans for accident scenarios described in MIRP greatly help actual incident management, so in this paper the main sections are highlighted, such as reconnaissance, rescue and intervention strategies. [8]

Reconnaissance

The primary task is to organize and perform reconnaissance, which always has to cover the following items:

- the number and location of the injured or the victims stuck inside (based on a headcount or consulting with the rescued victims);
- the location and direction of the exit and the extent of the damage to the technology;
- the concentration levels (identifying zones);
- description of the area (drainage map, slope of the area, accessibility of the routes, as it can happen that in case of a spill in the engine room or the refrigeration room, the extent of the damage can be decreased by blocking the doors and the ventilation).

In a corporate environment (in dangerous establishments, in below-tier establishments) the potential incidents involving hazardous materials are allocated codes in the scenarios. To compile a database, only the necessary and sufficient information should be collected. In an accident, collecting unreasonably too much data can be a waste of time and does not facilitate emergency management in effect. If the continuous communication between the leaders of the incident response team and the reconnaissance team is guaranteed, the leader of the response team has to help limit information in order to identify the scenario by adhering to unambiguous questions. [9]

In practice, reconnaissance, assessment, decision making and command form a continuous, so-called tactical cycle. The external parameters affecting the course of the accident can change for multiple reasons and the leader of the response team has to respond to these changes. He has to notice them and adapt to the changing circumstances.

The “situation” thus covers all the factors that must be taken into account during the intervention to avert and overcome dangers.

The situation is determined by:

- the incident and the inherent risks;
- the necessary response, which specifies the intervention personnel and equipment.

The situation is influenced by: the "general situation" (location, time, weather, number of staff, etc.).

At the scene of the fire or the accident, we have to be prepared for special circumstances in the presence of anhydrous ammonia. A smooth intervention can be expected if:

- the training and experience of the intervention team includes knowledge about hazardous materials;
- the equipment (personal protective equipment and other tools) are suitable for special interventions involving hazardous materials;
- extinguisher suitable for flammable materials is available.

From the viewpoint of the response team, it is important for them to become acquainted with the whole cycle, including the stages of compressed gas, compressed liquid and vacuumed gas. [8]

Specifying Personal Protection
Points to Consider when Choosing Protective Equipment

In the case of intoxication, it is essential how long the human body is exposed to the effects of the toxic materials like ammonia, which is called exposure. The leader of the response team can determine the level of protection with the help of Table 3.

Table 3. Concentration of anhydrous ammonia vapor and its effects on the human body. [10]

Exposure (ppm)/ percent by volume (m/m %)	**Effect on the Body**	**Permissible Exposure**
25 ppm 0.0025 percent by volume	Adverse effects highly unlikely	–
50 ppm 0.005 percent by volume	Detectable by almost all persons. Some people complain of nose irritation after 5 minutes of exposure	No injury from prolonged, or repeated exposure
134 ppm 0.0134 percent by volume	Most people experience dryness and irritation of nose, throat and eyes	Eight hours maximum exposure
400 ppm 0.04 percent by volume	Moderate throat irritation	–
500 ppm 0.05 percent by volume	Immediately dangerous to life or health (IDLH)	One hour maximum exposure
700 ppm 0.07 percent by volume	Coughing. Severe eye irritation, if not treated, may lead to partial or total loss of sight	One hour maximum exposure
1000 ppm 0.1 percent by volume	Directly caustic to airway	No exposure permissible

1,700 ppm 0.17 percent by volume	Serious lung damage, death unless treated Laryngospasm	No exposure permissible
2000 ppm 0.2 percent by volume	Burns and blisters skin after a few seconds of exposure	No exposure permissible
5000 ppm 0.5 percent by volume	Death by suffocation within minutes	No exposure permissible

In interventions involving hazardous materials, personal protection is of utmost importance. No intervention can be conducted in the vicinity of hazardous materials without protective equipment. On the basis of the risk level and worker comfort, four levels of protection can be differentiated, as can be seen in Table 4.

Table 4. Levels of protection recommended by EPA (it is valid for ammonia too). [11]

Level A protection (This level is preferred in the presence of ammonium gas.)	**Level B protection**	**Level C protection**	**Level D protection**
encapsulating, whole-body chemical protective heavy garment (with insulation) self-contained compresses air breathing apparatus with a full face mask boots providing chemical and mechanical protection double layer protective gloves protective helmet communication device	encapsulating, whole-body chemical protective garment (with insulation or filtration) self-contained compresses air breathing apparatus with a full face mask boots providing chemical and mechanical protection double layer protective gloves protective helmet communication device	encapsulating, whole-body chemical protective garment (with insulation or filtration) full face gas mask with adequate filters boots providing chemical and mechanical protection double layer protective gloves protective helmet communication device	whole-body chemical protective light garment (with insulation or filtration) full face or half face gas mask with adequate filters (with safety glasses) protective boots protective gloves protective helmet

Out of the levels of protection, the most optimal has to be selected by considering safety, worker comfort and financial factors.

When wearing gas-tight protective clothing, calculating with an average rate of work, at least 10 minutes have to be allocated for chemical decontamination after performing the intervention.

Life-Saving

Although chronologically lifesaving is preceded by some other tasks, it comes first in the order of priorities even in an intervention involving hazardous materials for both humanitarian and legal reasons.

Victims can be considered in immediate danger to life if they cannot escape by their own efforts without help, which can cause their death or severe injuries.

Victims are in indirect danger to life if the can escape on their own from a direct danger or if without being rescued, the danger would become immediate. Both types of victims must be rescued. These factors also have to be examined when the rescue order is determined. [12] The symptoms of ammonia intoxication are summarized in Table 5.

Table 5. Symptoms of ammonia intoxication. [13]

Airways, lungs, and chest:	Cough Chest pain (severe) Difficulty breathing Rapid breathing Wheezing
Body-wide:	Fever
Eyes, ears, nose, mouth, and throat:	Tearing and burning of eyes Temporary blindness Throat pain (severe) Lip swelling
Heart and blood:	Rapid, weak pulse Collapse and shock
Nervous system:	Confusion Difficulty walking Lack of coordination Restlessness Stupor (altered level of consciousness)
Skin:	Bluish-colored lips and fingernails Severe burns if contact is longer than a few minutes
Stomach and gastrointestinal tract:	Severe stomach pain Vomiting

Designating Escape Routes and Assembly Points

Designated escape routes and evacuation assembly points must be accessible at all times. Always the safest routes have to be designated for rescue. Special attention has to be paid for the direction the hazardous material like ammonia spreads in, its location and based on them, the protection and decontamination of the victims must also be taken care of. Before life-saving, proper medical care has to be arranged for, so that the victims can be provided with immediate care after being rescued. When designating the escape routes, it has to be ensured that rescue and other activities do not interfere with each other. It would be reasonable to assign a rescue commander in the command team, who organizes and coordinates these activities to make them more transparent. The next part summarizes the urgent tasks in the case of ammonia intoxication.

What to do in case of ammonia intoxication? [14]

- When ammonia poisoning is suspected, victims should be led out of the contamination zone as quickly as possible.
- It is important that those helping them should be wearing adequate protective clothing, so as not to become victims themselves.
- Oxygen – if it is available – must be administered to victims while rescuers await the arrival of an ambulance.
- Irritated eyes must also be flushed with plain or saline water for 5 minutes. Remove contact lenses if they are being worn by affected persons.
- If there has been skin contact with ammonia, it is essential that the skin be decontaminated as quickly as possible. Clothing must be removed and the skin must be flushed with water for at least 5 minutes.

Performing Rescue

The command team and the intervention units have to pay due attention to the fact that they are responsible for not just their own safety, but also that of the citizens, the passers-by and the staff. Even if legally not spelled out, practically the rescuers are also part of the response and they can facilitate it with their attitude and prior knowledge. The entire personnel involved in the response have to be prepared for life-saving, which entails a significant amount of regular trainings together with the appropriate technical background. They need to have a thorough, practical, effective knowledge of the use of rescue equipment as well as the basic and special rules of the rescue. Long and frequent practice is needed until the use of rescue equipment becomes automatic. It is indispensable in the rescue of victims in potentially poor psychological conditions.

A certain amount of pedagogical knowledge might also be useful, because the victims to be rescued have to be provided with certain information, otherwise they would be less willing to cooperate. Little time is available to communicate relevant, brief information, which should be sufficient to start the rescue of the victim.

The Strategy and Tactics of the Intervention

The success of the intervention basically depends on the smooth operation of command and control. The incident commander is responsible for everything that happens during the intervention, thus for the effectiveness of the intervention. Intervention strategy incorporates all the goals of economic entities that aim at successful response, set out in the disaster management act. This strategy is realized by certain tactical elements. The tactics of the intervention encompasses a set of actions following a series of decisions, which deploy the right forces and resources to the right place at the right time. Thus, the incident is resolved within the shortest possible time without causing further damage. [8] [9]

Tactical methods

Defensive method includes:

- eliminating ignition sources;
- vapour suppression (dilution with water mist, controlling direction of flow);
- confinement or diversion, within the defined area;
- information;
- evacuation if needed.

Offensive method includes the following (the list is not inclusive):

- trouble-shooting to slow down or stop the leakage;
- keeping materials closed in their own container or package;
- clean-up processes. [8] [9]

Conclusions

The success of the intervention is primarily dependent on the smooth operation and effectiveness of the intervention units. It is important to note that the incident commander bears responsibility for everything that happens until somebody else takes over control. All types of ammonia scenarios are possible in cold-storage facilities due to the technology used. As can be seen in Figure 1, depending on the concentration, it can be immediately lethal or it may not even pose a health risk. A characteristic of ammonia incidents in cold-storage facilities is that the release can be liquid, vapor as well as gas, but the incidents are well manageable with proper reconnaissance, protective equipment, tactics and the suitable plans. It is of utmost importance that the first responders are well-prepared, their equipment is well-maintained and proper for the intervention.

The Government Decree of Hungary 219/2011. (X. 20.) on the protection against major accidents involving dangerous substances [1] requires establishments using a dangerous amount of ammonia to assemble and train an incident response team. The potential incident scenarios are detailed in the Internal Safety Plan (ISP) or in the Major Incident Response Plan. The Firefighting and Technical Rescue Plan (FTRP), which is based on ISP and MIRP, together with the joint drills ensure successful interventions. The authors plan to continue this series of articles, focusing on industrial accidents involving ammonia.

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Indoor Mobile Robot Navigation and Obstacle Avoidance Using a 3D Camera and Laser Scanner

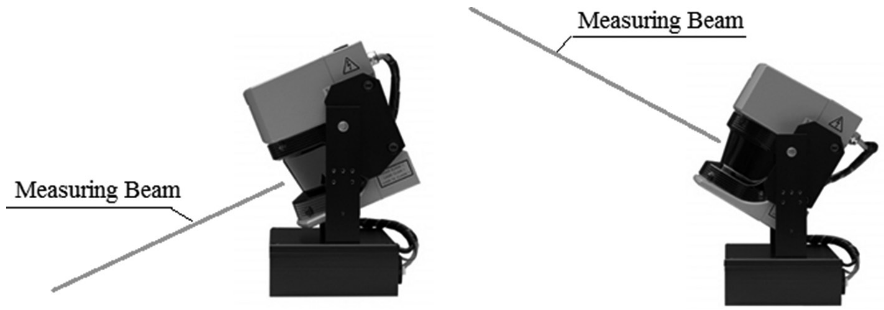
Peter KUCSERA[1]

Thanks to the developing sensor technology in mobile robot navigation and obstacle avoidance there are new and affordable solutions which can be used to accomplish smooth, safe and reliable robot movement in an indoor environment. A laser scanner is a commonly used sensor for detecting obstacles as well as for navigation, but a laser scanner is unable to detect all the different obstacles and terrain features by itself. In this article complementary sensors are examined, on a real mobile robot platform. Communication between the sensors and the controller and the basic control possibilities are also discussed. Finally, an advertising mobile robot is described.

Keywords: *Mobile robot navigation, obstacle avoidance, Laser Scanner, 3D camera, industrial communication, PLC, industrial sensors*

Introduction

In map based autonomous mobile robot navigation a key sensor is always a precise distance measurement sensor, which can scan the area in front of the robot. For this purpose, the most commonly used sensor is laser scanner or LIDAR. The typical method to measure distance is based on time-of-flight measurement. A wave packet is transmitted and having been reflected from the target it gets back to the transmission point and is sensed. Knowing the propagation speed of the wave and the running time, the distance can be calculated. This method is called Time-of-Flight (TOF) measurement. Transmitting sound causes slow and inaccurate measurement, so usually laser light is used. To accomplish two dimensional scanning, a rotation mirror makes the measuring beam scan in a given opening angle. The problem with this sensor is it can only scan plains, so three dimensional scanning requires some additional mechanics to bend the sensor body and change the vertical angle. (Picture 1)



Picture 1. Laser Scanner bending mechanism. [1]

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With this extra mechanism 3D scanning can be done, but the measurement speed for scanning the whole area in the front of the robot increases considerably.

An experiment was done, using an SICK LMS100 laser scanner. This is one of the smallest and cheapest scanners on the market with 20 m measuring range and 0.25° phase resolution in 270° scanning angle. A 2D scanning takes at least 20 ms, so if more measurements have to be taken with different bending angles, and the mechanics need some time to reach the desired position, the 3D scanning can take a second or even more. If the robot is moving, such a long measuring time is not acceptable.

Laser scanners not only measure distance in different angles, but the reflected signal strength (received signal strength indicator – RSSI) can also be measured. The RSSI value can be immensely useful to accomplish beacon-based navigation. If special reflectors are installed in the area where the robot is moving, the robot can relate its position to the reflector, by detecting higher RSSI, and measuring the distance of the reflectors. (Figure 1) For this purpose the laser scanner has to be installed horizontally at the height of the reflectors, to ensure sight between the scanner and the reflectors.

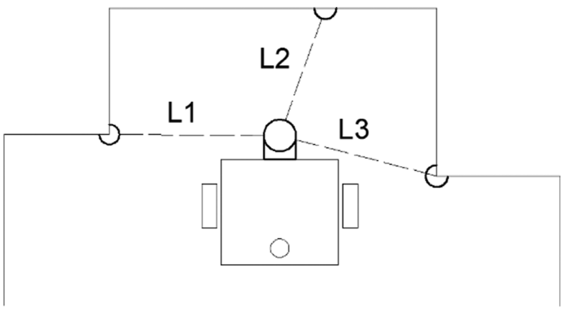


Figure 1. Indoor beacon based navigation measuring RSSI by detecting reflectors.
(Source: drawn by the author.)

Because of the above mentioned reasons, the horizontal installation of the laser scanner is recommended to ensure fast measurement and navigation. An additional bendable laser scanner for obstacle detection could obviously be useful, but it also increases the price significantly.

Complementary Sensor

There are cheaper sensors that can substitute for the bendable laser scanner, and can even work faster and more reliably. On Figure 2 typical obstacle types can be seen.

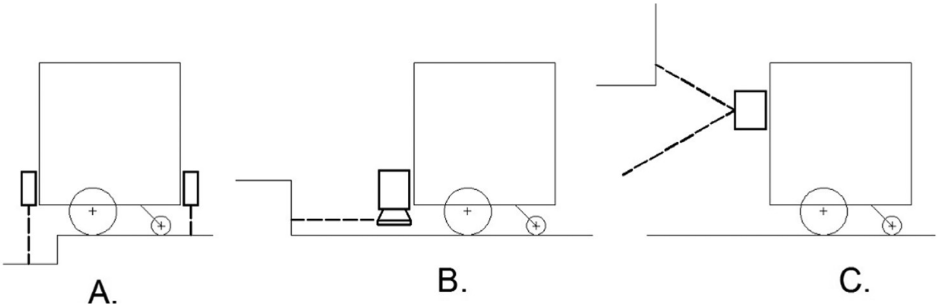


Figure 2. Typical obstacle types, and possible sensor solutions.
(Source: drawn by the author.)

Ditch detection can be done using short range sensors on the front and back of the robot. (Figure 2/A) Since there is no need for point-like measurement, ultrasonic range finder can be used. In case of short distances (~10 cm) one measurement can be done in a few milliseconds.

If the laser scanner is installed at a relatively low horizontal position, it can detect ground obstacles, steps, but it cannot detect obstacles located higher than the horizontal measuring plain. (Figure 2/B)

There is a need for a sensor which can "see" a 3D area in front of the robot. Using these measurements and considering the physical dimensions of a robot a proper path can be planned.

The most common method for 3D image acquisition is stereo vision, developed in the last decades by many researchers and engineers. The big advantage of stereo vision measurement is that it doesn't need any emitted signals, there are no difficult mechanical structures and moving parts, and it achieves high resolution and simultaneous acquisition of the entire range image. However, stereo vision systems still need custom trimming for the given environment, which makes general purpose implementation difficult. There are different stereo vision solutions on the market, but they are expensive and not too easy to synchronize.

Because of the progress of time-of-flight vision systems, nowadays a new technology, 3D matrix cameras are available at an affordable price (much cheaper than the stereo vision and laser scanners). [2]

The Photomixing Detector (PDM) cameras operate on the concept of TOF, and consist of an illumination source emitting modulated infrared light, an optical lens and a PDM chip. The PDM chip is a special complementary metal-oxide semiconductor (CMOS) pixel array which can detect the phase shift between the transmitted and received light and from the phase shift time and distance from the reflection point can be calculated. (Figure 3) [3]

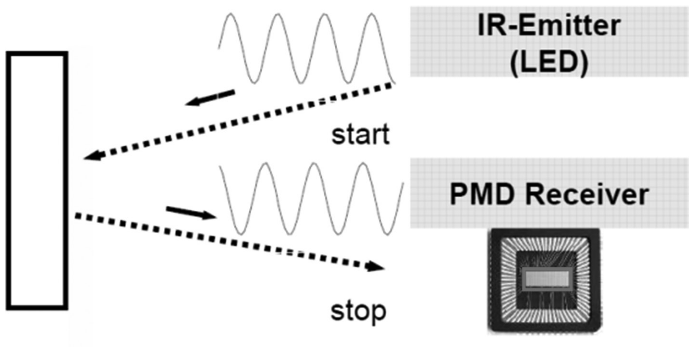


Figure 3. Working principle of the PDM time-of-flight camera. [3: 2]

IFM O3D201 PDM 3D Camera

The tested camera is an IFM O3D201. It has 64 × 50 pixel resolution, 20 Hz sampling rate, and about 6 m measuring range. The angle of aperture is 30° horizontally and 40° vertically. For reliable detection the object must be detected by at least two pixels. (Table 1) [4]

Table 1. Field of view size (mm). [4]

Measuring distance [mm]	View size [mm]		Average pixel [mm]			Minimum surface [mm]		
	Length	Width						
500	420	290	6	×	6	11	×	11
1000	840	580	11	×	11	22	×	22
2000	1670	1150	22	×	22	44	×	44
3000	2510	1730	33	×	33	65	×	65
4000	3350	2310	44	×	44	87	×	87
5000	4190	2890	55	×	55	109	×	109
6000	5020	3460	66	×	66	131	×	131

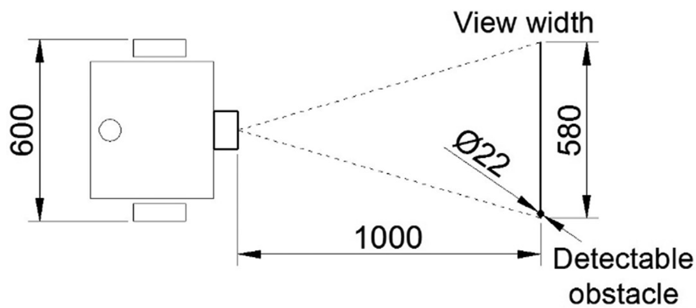


Figure 4. Detecting obstacles using O3D201.
(Source: drawn by the author.)

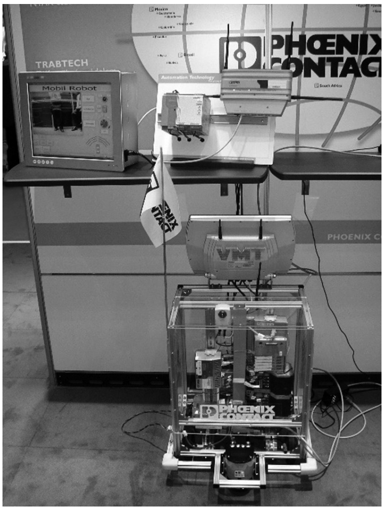
From the Table 1 and Figure 4 it can be seen that with O3D201, a small mobile robot (~600 mm wide), can detect obstacles when they are about 1 m away, but at this distance a 22 mm reflecting surface is needed. If the object is smaller, the robot does not detect it, but when it is closer, it falls out of the view of the 3D camera, and probably causes the robot to run into it. The real measurements with the camera show that even much smaller objects can be detected, but the reflecting surface quality also influences the size of the detectable object. A more expensive 3D camera with better resolution can solve such problems. This example only explains the limitation of the camera used.

Camera Interface

There are two IP ports used for the interface of the camera, one for setting up the camera, and one for getting the image data. The two ports are interfaced completely separately, with the exception that the camera trigger in manual mode is done through the settings port. As default, the settings port is set to 8080, and the data port is set to 50 002, but these can be changed with a configuration software, like the IP address. In addition to the two network interfaces, the camera also has a manual trigger and several IO ports with other purposes. The settings port is interfaced with XML-RPC commands. The camera manufacturer supplies a configuration software and a software library to make the integration easier.

Experimental Mobile Advertising Platform

In this article a real mobile robot application is described, which has been built at Óbuda University, in Hungary. The aim of the robot is to advertise companies at fairs and exhibitions by moving between visitors, playing advertisement videos, and carrying leaflet holders. It is essential for the robot to be absolutely safe. It is not allowed to run over the visitors, or to move to other companies’ stands. The accomplished system can be seen in Picture 2.



Picture 2. Advertising mobile robot platform.
(Source: photographed by the writer.)

Control

The controlling system is based on a Phoenix industrial controller (Programmable Logic Controller – PLC). A medium class PLC is used, which can handle Ethernet TCP/IP and RS232, serial communication. There are on-board integrated I/O-s and industrial bus couplers, so with connected extension modules new functions can be integrated. Only two servo drive modules (connected next to the PLC) are needed to handle the servos. This results in a very flexible system, which can be easily improved. Our whole controlling algorithm required only 32% CPU usage, so there is still opportunity to improve the program. It is really practical that the Ethernet port is integrated, since it makes it easy to communicate with other devices like the laser scanner, the 3D camera and the operator panel (Human Machine Interface – HMI).

Actors and Mechanics

The simplest mechanical structure was chosen, which has two independently driven wheels by two brushed DC motors. A third support wheel is used to make the platform stable, and support it. Encoders were used to have feedback from the wheels. The wheel speed is controlled by the drives using PID[2] closed control loop. Applying this structure has a great advantage. From the rotation of the wheels, when they are not slipping, the position can be calculated and used for navigation.

Additional Sensors

As it was mentioned before, for ditch detection an ultrasonic distance measurement sensor can be used. A TURK industrial sensor was chosen with a measuring range of 3–30 cm, and 4–20 mA analogue output.

The robot has a moving frame around the robot body. If the robot bumps into something, the frame movement can be detected by inductive proximity sensors (and the frame also decreases the collision force).

At exhibitions and fairs a colour detecting sensor can also be installed to detect ground colour. With this sensor, the robot can be kept on a coloured carpet.

Communication

Standard Ethernet communication was used for the whole system. Since the PLC, the laser scanner, the 3D camera, the operator and a webcam were connected, a switch was needed to connect these components together. Standard WLAN communication was used to communicate with the operator. In the system, industrial Ethernet components were used. This equipment is more expensive than the office components, but it is more reliable, it is easier to handle them, and they also have some extra functions. When the communication between the laser scanner and the PLC was tested, it was possible to mirror one communication port of the switch to another. This way, with a network analyser program, we could see the TCP/

2 P: proportional, I: integral, D: derivative

IP packages between the two communicating devices, although the packages were not sent to our computer. The WLAN devices have a fast roaming function, so when a large area has to be covered by more than one Access Points, the client can switch faster between them.

Power Supply

In case of a mobile robot, providing energy for the electric systems is quite an important problem. On our robot we have two DC motors with 120 W maximum power consumption. We also placed an industrial PC on the robot, which has about 80 W power need. Compared to these two loads the power consumption of other components is negligible. At least one hour continuous working is needed, so a 12 Ah maintenance-free lead-gel rechargeable battery can supply the system properly.

Operator Panel (HMI)

To operate the system, an operator computer is used. On this computer, it is possible to monitor the state of the robot, manipulate its behaviour, switch to manual mode and give commands manually, and also see the pictures coming from the camera which is on the robot. Reading values from the PLC is possible by using a special server program, called OPC server. The OPC server gives us an open source platform to read the PLC registers. The visualisation of the read values can be accomplished with an embedded software, but in industry, there are ready-to-use software packages, called SCADA software. Since we used a Phoenix Contact Controller, it was logical to use the SCADA of the same company which is called Visu+. With Visu+ it was simple to establish communication with the PLC, reading and writing registers, and also to visualise the picture of the camera.

The whole control system structure with the main components can be seen in Figure 5.

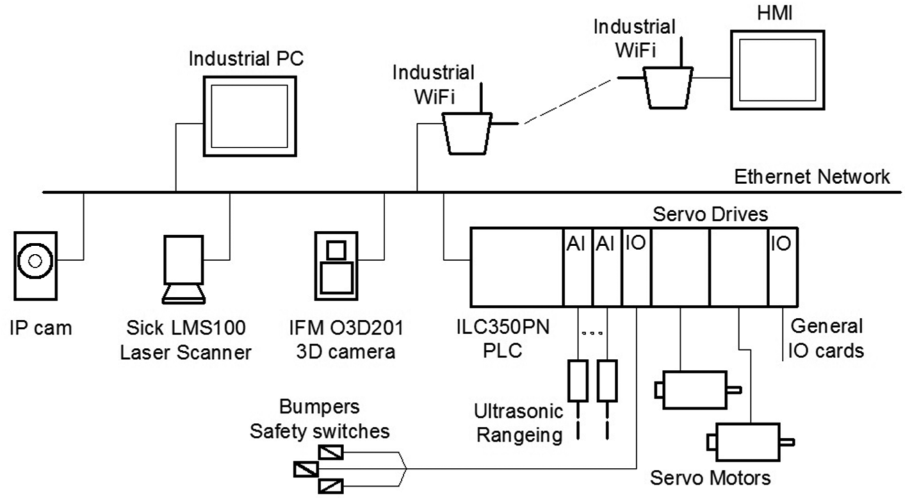


Figure 5. The structure of the advertising mobile robot platform.
(Source: drawn by the author.)

Controlling Algorithms

The control of the robot can be divided into two main parts:

- Obstacle detection and avoidance and safety control;
- Navigation, position control and path tracking.

The robot can detect obstacles with the laser scanner, in which different zones can be defined, and if an obstacle is detected in a zone, a two-state output of the scanner changes logical state, and this signal can be used in the safety controller.

The data measured by 3D camera can also be read and obstacles can be detected. For this, a trigger has to be sent to the camera and the IP packages coming from the camera have to be received and processed.

The ultrasonic range sensors and the bumper are also wired to the safety controller, and an emergency switch is also installed. The emergency controller has the right to switch off the drives and, in case of a collision, initiate a short back movement. This part of the program has to be run on a higher priority task and cannot be overridden by the rest of the program.

The actual position can be calculated from the wheel movement, but this calculation always has some errors, and the errors are integrated. Detecting the reflectors with the laser scanner, beacon based navigation can be accomplished (but in case of this measurement it has to be considered that the robot is moving). Using these two methods, fast and accurate positioning can be achieved. The robot has to follow a predefined path. If there is an obstacle on the path, the robot stops, and waits. After a given time, the operator is warned. The operator can switch to manual mode and using a live picture coming from an IP camera, the robot can be controlled and can bypass the obstacle.

The block structure of the control algorithm can be seen in Figure 6.

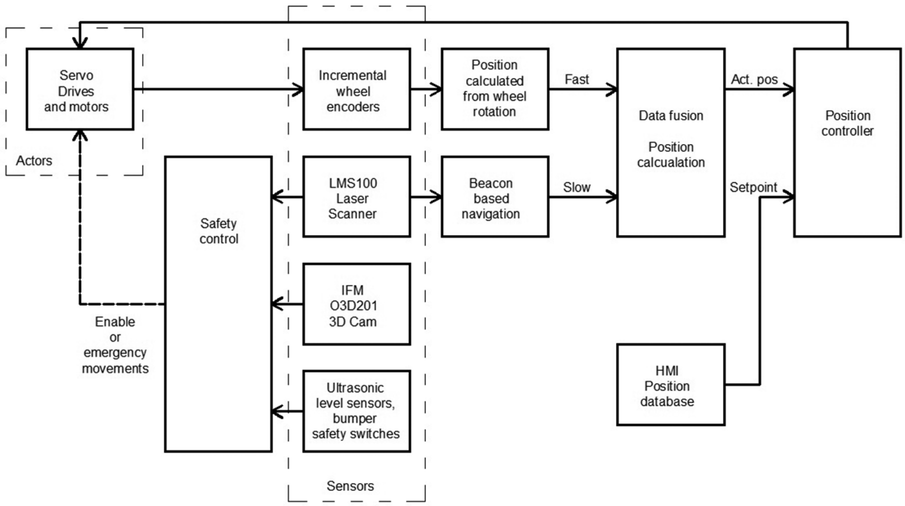


Figure 6. The block diagram of the advertising mobile robot control.
(Source: drawn by the author.)

Summary

In this article, an autonomous advertising mobile robot development was introduced. The aim of the project was to develop a working advertising mobile robot platform for exhibitions. Mainly industrial components were used in the robot. The navigation is based on a laser scanner, which detects special reflector beacons and calculates its position from these reference objects. The obstacle avoidance is accomplished with a 3D camera and ultrasonic distance measurement sensors. The main controller is a PLC, the communication is based on industrial WLAN, and Ethernet components. For the operation and manual control an industrial PC with SCADA software is used. The project has been exhibited with great success at many fairs and exhibitions.

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Proliferation of Offensive Cyber Weapons. Strategic Implications and Non-Proliferation Assumptions

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The development, acquisition and deployment of cyber weapons is becoming a routine activity of national military and law enforcement communities. This leads to a demand to introduce new strategic and regulatory regimes based on solid legal and policy structures. However, technical and legal experts face several complications when trying to meet these demands. The article gives a cursory overview of the particular difficulties and potential pathways to a solution with regard to cyber weapons use. Special attention is devoted to the international efforts involving Hungary.

Keywords: *legal review, arms race, cyber arms control*

Introduction

Since the early years of 2010s, nation states have been increasingly open about exploiting the strategic advantages of cyberspace as a domain of national interest. Facilitating the digitalization of the economy and commerce, the operation of public infrastructures and services have been integrated into national development policies. As a result, increasing volume of valuable assets are reachable in or through cyberspace. This also means that these are up for grabs and national governments are obliged to provide for some means of protection. Cyber weapons, most basically software technology, enable a wide variety of actors to fulfil both kind of efforts and therefore their role has undeniably risen recently. Nation states need to find solutions for how to integrate cyber weapons into their strategic arsenal, while they also have to install mechanisms to limit the detrimental and damaging impacts of cyber weapons used against them.

Difficulties start not only at the technical detection and elimination of malware from cybered systems, but also at how to analyze, understand, designate and regulate all these control mechanisms. In parallel, the legal expert communities have devoted more and more attention to the legal definition and the lawful applicability of cyber weapons, especially in the context of international conflicts. All these current trends illustrate a large scale overall process of strategic thinking and nascent norm building in regulating nation state use of cyber weapons.

Despite the greater willingness of experts and decision makers to openly discuss the use of cyber weapons, with regard to the inherent national security sensitivity, abundant authoritative data is still hard to come by. Major differences linger between and often within particular security communities. Cybersecurity and cyber strategic thinking is in a nascent phase, according to security and strategic studies researchers, this area is at a pre-strategic stage.

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This article is not an in-depth analysis of strategic cyber issue areas. By giving a brief introduction into the evolution and the proliferation of cyber weapons, the article rather seeks to illustrate that one of the consequences is a shift towards offensive strategic thinking and an increasing risk of conflict in cyberspace. Consequently, it is necessary to develop a more profound understanding and transition between the foundational technical, legal and strategic approaches of cyber weapons and force development. This is the first step towards building national military cyber strategies without upsetting international strategic stability. Through the eye of the strategist, one fundamental question is whether traditional strategic concepts and strategies can be applied in cyberspace. Following this deductive logic, these concepts in cyberspace seem to have limited applicability in cyberspace. Thinking inductively, a more viable option is the integration of the expertise of the technical epistemic community. Finally, without in-depth analysis, this integrative methodology seeks to demonstrate the interplay between the motivation, opportunities and limitation of nation states when drawing up strategy in cyberspace.

Hungary like every country is concerned in cybersecurity. This article also aims to link relevant Hungarian academic, institutional or strategic developments to this general strategic approach discussion of cyber weapons.

The first part starts out with the technical approach to cyber weapons by explaining why even those aware of all the technical intricacies are often of different opinion. Next, some of those comprehension problems are examined that arise when it comes to the legal definition and regulation of the use of cyber weapons. In the third section, the historical context of cyber capability evolution is introduced, followed by the strategic consequences thereby induced. The last part outlines the emerging international efforts into dealing with these strategic challenges by applying the existing arms control mechanisms or strategic application of technical mechanism.

Defining Cyber Weapons. Technical Aspects

As of today, there is no consensus as to what constitutes a cyber weapon or cyber weapons system, however, this is not unique to cyberspace. Many analysts agree that much of the confusion is due to two rudimentary facts. First is the lack of a generic definition of kinetic weapons in military strategies or legal codes. By default, the emerging conceptual approach applied in cyber weapon debates is a functional one, cyber weapon is any software component *used or designed to do harm*. This line of argument will be continued in the section on legal issues. As an illustration, an often cited example conceived by a legal expert at the Italian Ministry of Defense shows this trend: "… [an] *appliance, device or any set of computer instructions* designed to unlawfully damage a computer or telecommunications system having the nature of critical infrastructure, its information, data or programs contained therein or pertaining there to, or to facilitate the interruption, total or partial, or alteration of its operation." [1: 22]

The other source of confusion when defining cyber weapons is that the terminology and concepts used in cyber weapon discourse are directly taken over from strategic thinking based on conventional weapons or weapons of mass destruction. When it comes to cyberspace, though, these analogies are dysfunctional at several points. Terms used in legal and policy paradigms like "war", "weapon" and "destruction", "attack" or "deterrence" play out differently in cyberspace. Moreover, the usage of these terms is wide ranging and unconsolidated. For example, the term "cyber warfare" is used to describe the use of the cyber domain to conduct military operations ranging from the cyber equivalent of logistical convoys to the delivery of violent military attacks. [2]

Alternatively, as malware analysis methodology becomes increasingly sophisticated, a narrower and more bottom-up technical and thus more factual approach might take the place of business as usual strategy formation. Dorothy Denning from the Naval Postgraduate School, one of the hubs of cyber strategic thinking, was among the first discussants from the technical community who called attention to the wider national security implications of cyber technology. Her cyber weapon classification is focused more narrowly on the type of malware and what it is used for. Denning distinguishes between offense-only cyber weapons that are *used* only for the purpose of attack or to cause harm, defensive weapons that are used primarily to protect against such attacks, and dual-use weapons that are used for both offense and defense. The first category includes most computer viruses and worms; Trojan horses; e-mail bombs; denial-of-service tools; exploit scripts and programs that take advantage of vulnerabilities such as buffer overflows to gain access; rootkits with Trojan system utilities, backdoors, and system log cleaners to cover tracks; and copyright crackers. Defensive cyber weapons comprise encryption, authentication, access controls, firewalls, anti-viral software, audit tools, and intrusion detection systems. She mentions some dual-use and defensive weapons such as supercomputers, encryption devices, TEMPEST, and stealth technology. [3] This differentiation, however, can be misleading and indeed highly challenging as many technologies can be characterized as dual-use, for example, penetration testing methods and exploits are used as defensive weapons too, or non-malicious code is easily converted into weapons through minimal change. In addition, cutting-edge cyber weapons are composed of several different kinds of combination of the above mentioned components.

What proves to provide more clarity as of the nature and potential division of cyber weapons comes from an increasing number of technical research based on advanced malware analysis. These research explore the construction and behavior of malicious software. The rationale behind this approach is the possibility to recognize typical patterns providing information about the identity and motivation of the perpetrators. The following modular division well reflects this approach: "A Propagation Method (Pr) is the means by which malware is inserted into a target network or system, such as an infected USB stick or email carrying a compromised attachment. An Exploit is code designed to compromise some aspect of a software system which allows third parties to effect unintended operations or consequences. A Payload is the code with a malicious purpose whose delivery and execution are the goals of any piece of malware." [4: 1]

A cyber weapon is the combination of these three elements designed to create destructive physical or *digital effects*. According to this research, as the core functionality of the code is linked to the payload designed to create digital or physical effect, the payload determines the category of the cyber weapon.

"This modular approach to understanding threat software reveals a promising correlation between highly targeted tools (such as Stuxnet) and comparatively simple malware used for bank fraud that might prove useful to both the policy and research communities." [4: 1]

The following table is taken from a legal study and besides accurately depicting the software components of malware, also serves the purpose of highlighting the fundamentally divergent legal and technical analytical approaches. [2]

Table 1. Illustrative examples of technical functional analysis of two cyber weapons. [2]

CYBER WEAPON	TECHNICAL CHARACTERISTICS
ZeuS Trojan ZeuS Trojan is the name given to a family of popular (with cyber criminals) software programs that are part of the larger body of "malware." While computer viruses are generally considered to be malicious software that disrupts the functions of a system, the ZeuS Trojan, like most Trojans, is configured to operate unobtrusively in the background of a system, where it intercepts banking transactions.	Installable program usually spread by phishing and website compromises. Works as a "man-in-the-middle" keystroke logger and form interceptor. Preconfigured to recognize user access to banking or other websites. Reports the user's log-in information (in real time) to a contral controller. Also allows for remote updating and execution of downloaded code.
Poison Ivy A "remote access tool" or "RAT," is a software application that allows a remote user to interact with a computer system as if the operator had physical access to the system. Poison Ivy is similar to the ZeuS Trojan, but has broader applicability as a general purpose "remote access tool" that is freely available on the Internet. It has primarily been designed as a low footprint tool that can be later configured by downloading modules to the client.	Free-ware distributed from an official website. Operates as "client-server" that allows control of a system by a remote operator. Capabilities include: Encrypted communication; Remote file browsing; Process injection; Key logging; Registry manipulation; Screen capture; Audio and video capture; Password stealing.; Proxy services. Payloads customizable by users The code required for initial compromise is very small. 10 kilobytes, but once loaded, individual components may be added depending on user requirements**.**

Another line of differentiation is between cyber espionage and cyber-attacks. Despite the technical similarity between the propagation method and the exploit used for espionage and offensive cyber-attack, most US scholarly and policy sources deny that espionage tools are weapons. It shows a fundamentally different strategic and policy attitude, most probably owning to the fact, that the US possesses the most advanced cyber espionage tools and it is intent on preserving the widest possible space to maneuver. European literature tend to be more sensitive towards espionage. Karlis Podins Lithuanian and Christian Czosseck German scholars define a cyber weapon as: "Data and knowledge that is capable of, designed to and executed with the intention to affect the integrity, availability *and/or confidentiality* of an IT system (target) without its owner's approval. The target's defense is overcome by abusing existing vulnerabilities in the target." [5: 3]

Reviewing the Hungarian academic literature on cyber weapons, both the technical details and the strategic significance of cyber-attacks have been analyzed thoroughly. Extensive legal analysis is still lacking though. Just to mention a few examples, CrySyS Lab the Hungarian academic research institute has become internationally renowned by first reverse engineering the Duqu malware. [6] The notion of cyber terrorism and its information technology arsenal are discussed, [7] as well as the probable tools and tactics used in a complex cyber-attack against Hungary. [8]

Legal Considerations

A previous chapter in the history of cyber weapon regulation goes back to the end of the 1990s, the first time when transboundary regulations concerning cyber capabilities were attempted to be introduced. The demand and debate materialized in several different areas. For example, the export controls regime of dual use technologies in in the US, dubbed 'crypto wars'. In the field of international nonproliferation law, Russia presented its initiative in the UN General Assembly First Committee in October 1998 calling for states to share their views regarding the "advisability of elaborating international legal regimes to ban the development, production and use of particularly dangerous information weapons." [10: 48] The Council of Europe in Strasbourg raised the possibility of limited cyber weapons controls in their draft Cyber Crime Convention. The so-called Budapest Convention obliges States to penalize offenses against the confidentiality, integrity and availability (CIA) of computer data and systems. The production, distribution, and possession of computer programs with which CIA-offenses could be committed would also be illegal under certain conditions. [3] The Cyber Crime Convention treats cyber weapons as a criminal issue, therefore falls beyond scope of the current analysis.

The legal procedure including the definition, categorization and use of cyber weapons is particularly problematic in military issues. The fast-changing nature and diversity of cyber weapons render any legal review based on the enumeration of weapons useless. Nevertheless, militaries keep listing concrete capabilities under the heading of cyber weapons. For a number of other reasons too, military legal experts are in a particularly difficult situation when they have to provide legal advice in concrete cases. Without going into elaborate legalistic analysis, in the case of the law of weaponry, the fundamental referent point on the development, acquisition and use of weapon systems is rooted in the Hague Convention (IV), 1907, in particular Article 22 of its annexed regulations, which states that the "right of belligerents to adopt means of injuring the enemy is not unlimited." Article 36 of the 1977 Additional Protocol I to the Geneva Conventions of 1949 (API) codifies the requirement to conduct legal reviews of all new weapons.[2] The other legal track derives from *jus ad bellum* and relates to use of force, however, it is beyond the scope of this article. [1] Moreover, military cyberspace operations raise the mixed issues of geography, sovereignty, criminal law, and civil rights. According to *jus in bello* criteria and the general principles of war,[3] legal advisers review weapons of war and the application of those instruments in order to ensure there will be no disproportionate negative effect on the civilian population and property, or unnecessary suffering to combatants. [1] When using cyber weapons, targeting, distinction, proportionality and neutrality are particularly difficult issues. In the Manual cyber weapons are defined restricted to malware that can cause destructive physical effect, excluding damage done to data: "cyber means of warfare that are by design, use, or intended use, capable of causing either injury to, or death of, persons. The "Methods" of cyber warfare are the cyber tactics, techniques and procedures, by which hostilities are conducted." [9: 141]

2 The United States is not a party to AP I, it does conduct legal reviews is consistent with the AP I requirement since 1974. [2]

3 Military necessity, distinction, proportionality, unnecessary suffering, perfidy, neutrality.

According to some experts, similarly to the technical approach the confusion arises from the attempts to define and regulate cyber weapons based on the analogy of kinetic weapon systems. It is difficult to identify the "entity" that would be characterized as a weapon. [1] Legal expert Louise Arimatsu gives a concise summary of the problem. "A weapon is generally understood as a device that is 'designed to kill, injure, or disable people, or to damage or destroy property." [13] Although this definition might adequately encapsulate traditional weapons that have been designed, when utilized, to have a direct kinetic outcome, it fails to capture the essence of what are generally regarded as cyber-weapons. This is because most of the malicious codes or malware that would fall within the parameters of a cyber-weapon are designed to have an indirect kinetic outcome which may, or may not, result in the listed outcomes. In other words, the malware itself is not designed to kill, injure or disable people nor, necessarily, to damage or destroy tangible property." [12: 97]

The other common point of reference in legal argumentation is the effect a malicious code is designed to produce as a basis for judgement. This approach transpires throughout the Tallin Manual in discussing whether cyber-attacks in general fall under the purview of the Law of War. In summary, it is both the offensive capability of the code and the desired effect that can determine if a cyber capability can be considered as a weapon, and thus whether its deployment is permissible or not according to the Law of War.

Proliferation of Cyber Weapons

Surveying the publicly available US secret service Congressional hearings since the mid-1990s reveals that the development and stockpiling of cyber weapons by certain nation states have proved to be a recurring national security threat indicator. [13] By 2007, for example, there were an estimated 120 countries working on cyber-attack commands, and in it was also predicted that on 10 to 20 years countries would be "jostling for cyber supremacy." [14: 123] Experts trace the evolution of cyber capabilities developed by major militaries back at least as early as the 1940s, though the nature of the attempts to penetrate computers and computer networks could be both defensive and offensive. In the 1960s, security analysts in the US Department of Defense developed a professional understanding of computer penetration by analyzing the security of the nation's time-sharing computer systems. In the course of time, this ability to detect the vulnerabilities of one's own computer systems has been turned into an offensive weapon system. [15] According to the one of the most often cited inventories of national cyber capabilities on the level of policy, doctrine and organization the number of these states, based on publicly available information back in 2013, was 18 in Africa, 16 in the Americas, 39 in Asia, 38 states in Europe, and 3 in Oceania. (Table 2) [16] It is important to note, however, that this data set is insufficient to paint an authoritative picture as the nature and maturity of these programs vary greatly by country.

Table 2. The number of countries possessing cyber capabilities in 2015. [13]
(Edited by the author.)

CONTINENT	COUNTRIES WITH MILITARY CYBER DOCTRINE, POLICIES OR ORGANIZATION	COUNTRIES WITH CIVILIAN CYBER DOCTRINE, POLICIES OR ORGANIZATION
Europe	Albania, Austria, Belarus, Croatia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Netherlands, Norway, Poland, Russian Federation, Slovakia, Spain, Switzerland, Ukraine, United Kingdom	Belgium, Bulgaria, Czech Republic, Iceland, Ireland, Liechtenstein, Lithuania, Luxembourg, Malta, Montenegro, Portugal, Republic of Moldova, Romania, Serbia, Slovenia, Sweden
Asia	China, Democratic People's Republic of Korea, Georgia, Indian, Indonesia, Iran (Islamic Republic of Iran), Israel, Japan, Kazakhstan, Malaysia, Myanmar, Republic of Korea, Singapore, Sri Lanka, Syrian Arab Republic, Thailand, Turkey, Singapore, Sri Lanka, Syrian Arab Republic, Thailand, Turkey, Viet Nam, Yemen	Afghanistan, Armenia, Azerbaijan, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, Cyprus, Jordan, Kuwait, Lebanon, Maldives, Mongolia, Nepal, Oman, Pakistan, Philippines, Qatar, Saudi Arabia, United Arab Emirates
Africa	South Africa	Burundi, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Madagascar, Mauritius, Morocco, Nigeria, Rwanda, Sudan, Swaziland, Tunisia, Uganda, United Republic of Tanzania, and Zimbabwe
Americas	Argentina, Brazil, Canada, Colombia, Cuba, United States	Antigua and Barbuda, Dominican Republic, Grenada, Jamaica, Mexico, Panama, Peru, Saint Vincent and the Grenadines, Trinidad and Tobago, Uruguay
Oceania	Australia, Fiji, New Zealand	

Stuxnet malware brought on a tectonic shift in cyber strategic thinking. There is little dissent among information security and industrial control system engineers on the breakthrough value of the complexity and the sophistication of the malware, as well as the fact that a cyber-attack caused physical destruction. [17] Iran's nuclear power plant capacities are directly related to its weapons potential, thus such intervention has strategic implications, and count as coercion against the country. Yet the appraisal of the strategic value of the Stuxnet attack is far from unanimous. Most critiques question the strategic degree of the physical damage and disruption, and its impact on the Iran's overall nuclear policy and international negotiation position. On the other hand, Martin Libicki pointed out the significance of Stuxnet from the wider strategic policy, namely the deterrence value of the attack. According to journalistic assertions, the attack was implemented by nation states, most probably the US and Israel, thus fulfilling two of the fundamental building blocks of retaliatory deterrence, the level of a nation's capabilities and its determination to use them.

Stuxnet attack has been a unique occurrence so far, at least based on publicly available documents. Another type of cyber weapon, nonetheless, has been detected at mass level. The so called Advanced Persistent Threats (APT) is difficult to detect, still since 2010 a growing number of APTs have been detected. There are several definitions of APT.

"Advanced: The hacker has the ability to evade detection and the capability to gain and maintain access to well protected networks and sensitive information contained within them. The hacker is generally adaptive and well resourced. Persistent: The persistent nature of the threat makes it difficult to prevent access to your computer network and, once the threat actor has successfully gained access to your network it is very difficult to remove. Threat: The hacker has not only the intent but also the capability to gain access to sensitive information stored electronically." [18: 1]

Considering the skills necessary to design, implant and maintain such a malware, along with the nature and volume of information so vacuumed from targeted information systems, ATPs can be considered of strategic significance, though not through its destructive capacity.

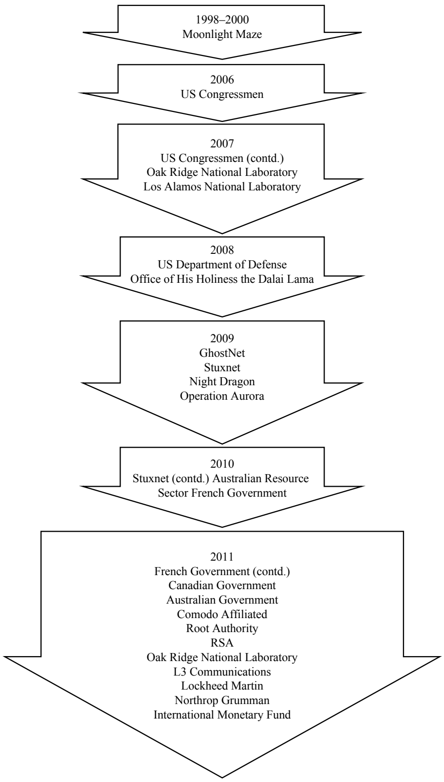

Figure 1. Major ATPs revealed. [18: 3]

The by now canonized list of illustrative cyberattacks on national critical infrastructures well demonstrates that cyber weapons are being deployed with ever growing audacity. This tendency is followed suit by the ever increasing stage of cyber capability development and doctrinal evolution of the defense policy of the countries concerned.

Over the past three years, through a multi-thronged development process the superior US cyber capabilities have been firmly established and integrated with other joint capabilities along the services and the reserve components. Just to highlight one momentous example, the Defense Advanced Research Projects Agency (DARPA), the Pentagon's main research and development organization launched a five-year, $500 million budget research plan to boost research into offensive cyber tools. [19] As Kaigham J. Gabriel, DARPA deputy director testified in 2012 "We need cyber options that can be executed at the speed, scale and pace" of other military weapons. [20: 8]

This new operational stage has been consolidated by the Department of Defense Cyber Strategy published in April 2015, and most recently, by the Department of Defense Law of War Manual issued in June 2015. The Manual focuses on *jus in bello*, law relating to the conduct of hostilities and the protection of war victims that is applicable to the United States, including treaties to which the United States is a Party, and applicable customary international law. [21] The document assesses law of war publications issued hitherto by different services within the military, as well as including conclusions based on consultation with allied nations' legal experts, and is serves as a DoD-wide resource for DoD personnel. As for cyber operations, the U.S. armed forces "are developing tools and capabilities' necessary to carry out its missions set forth in the latest DoD cyber strategy consistent with U.S. and international law." [22] Assessing the overall development in US military doctrines pertaining to cyber weapons, there is a shift towards the openly declared operational use of offensive cyber weapons, accepting even possibly lethal collateral damage, though with the intention and ability to try and keep unnecessary damage rate to the lowest possible level.

Strategic Implications

The strategic aim of the US technical and cyber capability development is declaratively to maintain its superior position vis-a-vis its peer competitors, mainly China and Russia. In terms of cyber weapons, however, relative capability positioning is not so obvious primarily for two reasons. It is common place that the more the number and complexity of computing devices applied, the more exploitable vulnerabilities exist in a system, which makes these inherently vulnerable systems extremely difficult and expensive to defend. The central strategic and policy model of deterrence by punishment as it is known from nuclear strategies is impossible to apply due to the nearly impossible task to unambiguously identify the culprits behind a cyber-attack. In sum, all these strategic determinants of the cyber environment contribute to the belief, mainly prevailing among major powers, that the volume and cutting-edge quality of cyber capabilities is necessary to deter cyber-attacks. By nature, the efficiency of cyber weapons is transitory, and the exploits of any cyber weapon are very specific to a system configuration. Hidden culpability as well as the relatively low costs and short time span demanded by cyber capability development all act as incentives to accumulate a stock of cyber weapons as extensive as possible. The escalatory nature of cyber conflicts became part of the emerging corpus of cyber security strategy literature.

Cybersecurity experts also point out that in terms of action-reaction cycle an arms race is also taking place between non-state malicious hackers and IT security experts. Although among traditional strategists there is no consensus, whether the classic theory of security dilemma is applicable, it is easy to recognize that cyber arms race is almost inevitable for several different reasons. As a result, the exchange of exploits through illegal markets has boomed over the last five-ten years. Illegal exploit research and selling have become lucrative business, nonetheless these mechanisms are shrouded by intractability. What makes matters even more complicated is that in certain aspects, nation states' interests lie more in preserving this fuzziness than bringing transparency and legal clarity. No wonder, that these phenomena alarm a wide variety of different communities ranging from IT security specialists and human rights activists to legal experts and national decision makers. With regard to such a wide range of interests, it is not easy to find optimal solutions.

Arms Control Approach

The discovery of Stuxnet malware and the frustrating results of deterrence strategy options also inspired further potential arms control and regulatory discussions. As already mentioned above, initiatives to restrict the development and acquisition of cyber weapons appeared at the end of the 1990s. Although the Russian proposals were refused by US delegates in the First Committee of the UN General Assembly (UNGA), the wording and content of the proposal got gradually modified, and under the title "Developments in the field of information and telecommunication in the context of security". With gradual changes, the non-binding resolution has been adopted by the UN General Assembly each year. In the resolution of 2001, Russia requested the establishment of a group of governmental experts (GGE) for a study to discuss possible cooperation measures. The second GGE was able to produce a consensus which highlighted the need to continue discussing further *norms* to address existing and potential threats in the sphere of information security. Norms here are meant to be gradually evolving voluntary patterns, though the ultimate Russian ambition is still to establish a binding treaty banning the development, production and use of particularly dangerous information weapons.

Based on the GGE report endorsed by the UNGA, the promotion of cyber security Confidence Building Measures (CBMs) entered the agenda of the regional organizations like the Organization for Security and Co-operation in Europe (OSCE) and Association of Southeast Asian Nations (ASEAN). The package of measures accepted so far are voluntarily carried out by participating states, and they are built around transparency of nation cyber security measures, and the establishment of bilateral and multilateral points of contact.

Policy and legal experts are highly skeptical about the feasibility of cyber arms control treaties. Beyond the ambiguities mentioned in the first part, enforceability, verification and rapid technological change are the most often cited reasons. The evaluation of arms control and disarmament regimes introduced into cyberspace has been given more attention recently. The Biological Weapons Convention and Chemical Weapons Convention are studied in search of useful analogies and lessons learnt. Arimatsu argues that the parties' motivation is different in arms control regimes from that of the Laws of War. In the previous case states are willing to restrain their capabilities in order to achieve military balance, while in the latter, the aim is to reduce the human suffering and unnecessary damage. [15] As the political and strategic climate change, states' political inclination might shift as well, as the precedent of earlier arms control regimes show.

There is also some progress in the regulatory regimes of cyber weapons, though its efficacy is highly controversial. Export controls on encryption stem from agreements made under the Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods Technologies. The recent round of agreement materialized in December 2013, when the 41 member states including Hungary and Russia, but not China, agreed on principles to control the export of software that can be used for surveillance. The motivation partly serves human rights by limiting the abuse of surveillance technologies produced in developed countries, and partly strategic to enhance the security of the producing countries by reducing the rate of surveillance technology used to spy on them. The agreement does not use the term cyber weapon, but the overly broad expression of "intrusion software," which is defined as "software that is capable of extracting or modifying data or modifying the standard execution path of software in order to allow the execution of externally provided instructions". It also concerns the cross-border use of technology used by the security research and practitioner communities.

Finally, responsible disclosure policy might offer strategic stability at national and international level. According to expert literature, ethical hacking is the earliest example of responsible disclosure. Offering bug bounty by software and hardware is becoming more common, but its amount often lag behind the price offered by nation states or criminals at hidden exploit market outlets. A new concept of coordinated vulnerability disclosure is gaining ground at governmental level. The Netherlands, for example, have launched a disclosure policy on websites of the Dutch central government. [23] International co-operation mechanisms have started to build around the same idea. In April 2015, at the Global Conference on Cyberspace in The Hague, Romania, the Netherlands, Hungary, and Hewlett Packard initiated a voluntary cooperation mechanism under the name Responsible Disclosure Initiative (Ethical Hacking). The cooperation works within the framework of Global Forum on Cyber Expertise, and it is open for others to join. The objective is to share experiences and lessons learned in cyber security mechanisms for responsible disclosure or coordinated vulnerability disclosure policies and discussions on the broader topic of ethical hacking.

Conclusion

Stakeholders are much more open about their cyber capabilities and strategic intentions and vulnerabilities in cyberspace. Cyber-attacks have become part of the national security agenda, which requires new and effective system-level answers, necessitating more transparency and co-operation, even self-restraint in using the available cyber weapons. Nevertheless, the cyber ability to develop or acquire cyber weapons is a strategic asset, the strategic insight and maturity on how to use these weapons is still wanting. The current period is often compared to the pre-strategic era of nuclear weapons between the 1940s and 1960s. Trust is lacking between nation states, or even between different national security communities within national borders. Strategists need to conceive how to balance the different interests on their national foreign and security agenda in an environment fraught with so far unseen technical complexities, existing legal paradigms are obsolete, and due to attribution difficulties the perpetrators are unidentifiable. Decision makers need to work out the trade-offs that best serve the overall national strategic framework. In conclusion, much more cooperative technical, legal and political-military analysis is necessary to achieve a higher level of strategic maturity both in deploying cyber weapons and in developing security strategies against their use.

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Unique Natural Values of the Military Training Area Záhories

Milota KUSTROVÁ[1]

The article presents the results of natural science research on plant and animal communities in the military training area Záhorie. Nineteen habitats of Community Interest and six habitats of National Interest have been recorded in the area. The paper underlines the importance of the existing military training areas and military activities for biodiversity conservation, and also notes the need to implement measures to rescue valuable habitats.

Keywords: *military district, military training area, biodiversity, military activity, Sites of Community Importance (SCI), flora, fauna, habitat*

Introduction

The public usually considers military training areas to be devastated landscape. This opinion is widespread especially among those who have never been to a military area, or who lack the necessary information. People are often convinced that military exercises in the military areas cause large-scale contamination by chemical or radioactive combat substances, fuels, destruction of vegetation and soil, killing animals or disturbance by excessive noise. These negative factors, if they do occur, usually affect only small sites within the military areas which are intensively used for training. Much larger areas of military districts, however, serve only as a "buffer zone" for the intensively used parts and military operations are almost never carried out there, or only irregularly and very rarely. Such extensive buffer zones are needed primarily for safety reasons. They often serve as important refuges for endangered species and communities. Human activities with negative impact on the natural environment, such as over-intensive agriculture and forestry, construction, industry and recreation, are excluded in the long term from the areas of active military operations. Moreover, the regular disruption of land cover during military operations supports the maintenance of several habitats of community interest (on Aeolian sands it often replaces the natural function of wind). Most animals (birds, mammals) are able to adapt relatively well to the occasional disturbance and noise resulting from military activities. Some rare species of animals find ideal conditions right at the shooting ranges. Sparse oak and pine plantations are an ideal habitat for them; therefore their populations here reach the highest abundance and density within the whole of Slovakia. Several rare species of plants and invertebrates are totally dependent on military activities which help to maintain their habitats.

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Basic Information about the Military District Záhorie

There are three military districts (MD) in Slovakia – MD Záhorie, MD Valaškovce and MD Lešť, with a total area of 54 200 hectares. MD Záhorie is the largest and most well researched military district. There are three smaller military training areas (MTA) – MTA Kuchyňa, MTA Turecký vrch and MTA Záhorie. (Figure 1)

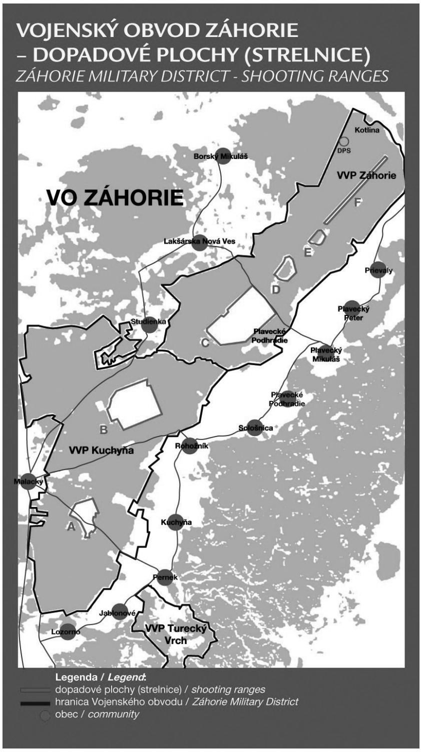

Figure 1. The map of the Military district Záhorie. [2]

Záhorie MD is Slovakia's oldest military district; it has been used for training the armed forces since 1923, hence before the large-scale intensive use of landscape. Since that time, the entire area has been used predominantly for military purposes. Other human activities have been restricted to services for the military area only. This very specific land use has resulted in conservation of a unique area of great natural value, which differs from the surrounding intensively used lowland landscape in terms of: [1]

- low level of fragmentation – it represents the largest continuous complex of a lowland forest in Slovakia;
- prevalence of natural and semi-natural ecosystems (forests, wetlands, grasslands, sand dunes);
- high diversity of habitats at different stages of succession development – frequently as a direct consequence of military actions;
- refuges of endangered wildlife (e.g. black stork) – many wildlife species have thrived here only thanks to the presence of the military area;

- natural water resources are still largely unspoiled by residuals of fertilizers and pesticides unlike in the adjacent agricultural landscapes;
- restricted access of public to the military area.

Záhorie MD is located in the central and eastern part of the Záhorská nížina lowland in western Slovakia; a small part also stretches over the Malé Karpaty Mountains. Its current size is 27 650 hectares. Záhorie MD is part of the geomorphologic unit Borská nížina lowland, which is a part of Záhorská nížina lowland. It stretches over the largest area of Aeolian sands in Slovakia with a total area more than 570 square kilometers. Under such specific conditions a diverse mosaic of extremely rare (and, on the territory of Slovakia, often unique) communities has evolved. Running and still waters and wetlands alternate with dry sand dunes. Thanks to extraordinary habitat diversity, there are a high number of species and communities with different ecological requirements in a relatively small area. Forest biotopes cover more than 72% of the area in a wide range of forest communities, from fen alder woods to dry pine-oak woods. [2] Nineteen habitats of Community interest and six habitats of National interest have been recorded in the area. (Table 1)

Table 1. Habitat types of Community interest in Záhorie Military District. [3]

Code	**Habitat type**
2340*	Pannonic inland dunes
3140	Hard oligo-mesotrophic waters with benthic vegetation of Chara spp.
3150	Natural eutrophic lakes with Magnopotamion or Hydrocharition – type vegetation
3160	Natural dystrophic lakes and ponds
3260	Water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation
3270	Rivers with muddy banks with Chenopodion rubri p.p. and Bidention p.p. vegetation
4030	European dry heaths
6410	Molinia meadows on calcareous, peaty or clay-silt-laden soils (Molinion caeruleae)
6510	Lowland hay meadows (Alopecurus pratensis, Sanguisorba officinalis)
7140	Transition mires and quaking bogs
7150	Depressions on peat substrates of the Rhynchosporion
7230	Alkaline fens
9190	Old acidophilous oak woods with Quercus robur on sandy plains
91E0*	Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)
91F0	Riparian mixed forests of Quercus robur, Ulmus laevis and Ulmus minor, Fraxinus excelsior or Fraxinus angustifolia, along the great rivers (Ulmenion minoris)
91G0*	Pannonic woods with Quercus petraea and Carpinus betulus
91I0*	Euro-Siberian steppic woods with Quercus spp.
91D0*	Bog woodland

*Explanatory notes: * indicates priority habitat types*
Code – European significant habitat code under Annex I of the Habitats Directive No. 92/43/EEC - Natura 2000 code; this is the four digit code given in the Natura 2000 standard data-entry form.

Thanks to the unique natural richness of Záhorie MD, parts of this area have been included in the NATURA 2000 network. In 2004, the Government of the Slovak Republic approved a "National list of proposed Sites of Community Importance" (SCI) and submitted it to the European Commission for endorsement. [4] The European Commission approved this proposal in 2007 for sites in Pannonian biogeographical region (to which Záhorie belongs as well). [5] [6]

At present, ten SCI with a total area of almost 5 000 hectares are located in Záhorie MD, while proposals of other sites have been elaborated. (Figure 2)

Figure 2. Proposed Sites of Community (SCI) in Military District Záhorie. [10]

Natural non-forest communities on open sand dunes are among the most threatened habitats in central Europe. In the area of Borská nížina lowland these communities represent a priority habitat of Community Interest *2340 Pannonic inland dunes* and a habitat of Community Interest *4030 European dry heaths*. Habitats of the sand dunes with open swards are characterized by the occurrence of several critically endangered plant and animal species creating unique communities.

The largest and best-preserved habitats of sand dunes and dry heaths within the whole of Slovakia are located right in the Záhorie MD, where they have been preserved largely thanks to the regular disruption of land cover during military activities. Four of the so called "impact areas" (shooting ranges) are included in the European network of protected areas NATURA 2000.

Flora of the Military District Záhorie

On the open (non-forested) sand dunes of the Záhorie MD rare plant communities occur over large areas. The living conditions are considerably difficult here, therefore these areas are colonized largely by the so called psammophyte species (preferring sandy soils or areas). They are adapted to extreme drought and high summer temperatures; therefore they are able to survive here. Priority habitat of Community interest 2340 Pannonic inland dunes is unique due to the occurrence of species such as Grey Hair-grass *(Corynephorus canescens)*, Wing-stem Spurry *(Spergula pentandra)*, Morison's Spurry *(Spergula morisonii)*, Wild Thyme *(Thymus serpyllum)* or a Feather Grass *(Stipa borysthenica)*. Among the rare species a Fescue *(Festuca dominii)*, Late-coming Pink *(Dianthus serotinus)*, Dillenius' Speedwell *(Veronica dillenii)* or Dwarf Everlast *(Helichrysum arenarium)* also grow here. Non-vascular pioneer plant species (the first to colonize the new areas during the initial succession stage) found here include the bryophyte Fire Moss *(Ceratodon purpureus)*, species of the Haircap Moss *(Polytrichum sp.)* and Racomitrium Moss *(Racomitrium sp.)*, as well as many terrestrial species of Cup Lichens *(Cladonia sp.)*. The second rare habitat of Community interest is the European dry heaths (4030) with the dominant abundance of the Common Heather *(Calluna vulgaris)*. Other species typical for this habitat are Black Yellow Late Broom *(Lembotropis nigricans)*, Hairy Greenweed *(Genista pilosa)*, Dyer's Greenweed *(Genista tinctoria)* and Common Broom *(Sarothamnus scoparius)*. [2]

The occurrence of some of the plant species, such as Alpine Bulrush *(Trichophorum alpinum)*, Meadow Bistort *(Polygonum bistorta)*, Wild Calla *(Calla palustris)*, Round Leaf Sundew *(Drosera rotundifolia)* and some Peat Moss species *(Sphagnum spp.)*, in Záhorie Military District is indeed remarkable as they represent the species that have been sustained in the region since last glaciation when there was a sub-arctic climate in Záhorie. The tiny Fen Orchid *(Liparis loeselii)* is one of the rarest species of Community interest that can be found within the area. (Picture 1) Moreover, the Záhorie MD harbours the largest population of a Fen Orchid in Slovakia.

Picture 1. Fen Orchid (Liparis loeselii).
(Photo by Jaroslav ŠÍBL)

With respect to wetland forests, especially 2 types of fen alder woods deserve attention – i.e. communities of sedge – alder wood and alder wood with Crested Fern *(Dryopteris cristata)*. These natural communities with relict species are nowadays in greater extent only present in Záhorie. They grow in slacks and along the Rudava River where the water table is high and they are also frequently flooded. While Common Alder *(Alnus glutinosa)* is a dominant tree species, Elongated Sedge *(Carex elongata)* is a characteristic species commonly found on the forest floor of an alder fen. Among the other frequently found species are: Greater Tussock-Sedge *(Carex paniculata)*, Fern *(Thelypteris palustris)*, Water Violet *(Hottonia palustri*s*)*, Bogbean *(Menyanthes trifoliata)* and European Frog-Bit *(Hydrocharis morsus-ranae)*. [1]

Fauna of the Military District Záhorie

Sand dunes are also a unique habitat for many species of animals, many of them being totally dependent on this type of habitat – meaning they cannot live in any other place. These are especially the psammophile (preferring sandy soils or areas) species of invertebrates, many of which in Slovakia are only found in Záhorie region.

The butterfly fauna (*Lepidoptera*) is extremely rich – 112 species. Among the most valuable species is the critically endangered Marsh Fritillary *(Euphydryas aurinia)*, Danube Clouded Yellow *(Colias myrmidone)*, Tree Grayling *(Hipparchia statilinus)* and Oriental Meadow Brown *(Hyponephele lupinus)*. Among the species typical for the Aeolian sands are Rock Grayling *(Hipparchia Alcyone)*, Grayling *(Hipparchia semele)* and Large Blue *(Maculinea arion)*.

Picture 2. Large Blue (Maculinea arion).
(Photo by Katarína KLIMOVÁ)

The richness and uniqueness of the entomofauna of Aeolian sands is characteristic also for other orders of insect. A detailed survey has been carried out especially for beetles *(Coleoptera)* – where more than 800 species were recorded, out of which many represent glacial relicts; for locusts and grasshoppers *(Orthoptera*) – 48 species; true bugs *(Heter-*

optera) – 227 species; and ants, bees and wasps *(Hymenoptera)* – 165 species. Majority of rare beetle species can be found in well-preserved old-grown forests. The priority species of Community interest inhabiting the area is an endangered Hermit Beetle *(Osmoderma eremita)* living exclusively in old hollow trees. Dying out trees, especially oaks are an ideal habitat for a European Stag Beetle *(Lucanus cervus)* and Great Capricorn Beetle *(Cerambyx cerdo)*. Remarkable are also Ant-lions *(Myrmeleontidae)*, which are similar to dragonflies. [2]

With respect to non-forest habitats, the Rudava River together with transition mires, alkaline fens and Molinia meadows with diverse invertebrate fauna rank among the most valuable. Several dragonfly species of Community interest have been recorded in the area. The Large White-faced Darter Dragonfly *(Leucorrhinia pectoralis)* can only be spotted at well-preserved fens. Unlike larvae of a Green Club-tailed Dragonfly *(Ophiogomphus Cecilia)*, which inhabit the sandy riverbed of the Rudava River, the larvae of our greatest dragonfly Balkan Goldenringed Dragonfly *(Cordulega sterheros)* prefer the small forest streams. *Cordulega sterheros* has been only recently recorded in Slovakia and all the records come from Záhorie region. Referring to vertebrates, the Rudava River is also a home of a rare Ukrainian Brook Lamprey *(Eudontomyzon mariae)*, which is only known from a few sites in Slovakia and is also ranked among the species of Community Interest. Altogether Rudava harbours 39 fish species, which represents the highest fish species diversity among all 55 tributaries of the Morava River. Fauna of amphibians and reptiles is also diverse (18 species). Sand dunes and dry heaths covered by sparse herbal vegetation with sporadic trees form an ideal habitat for reptiles. Literally with every step here one can meet Slovakia's biggest lizard – European Green Lizard *(Lacerta viridis)*. The Smooth Snake *(Coronella austriaca)* is rarer and often preys on the young lizards. Close to wetlands one can find Grass Snake *(Natrix natrix)*, which feeds on amphibians. These dry habitats are not very suitable for amphibians; only the Green Toad *(Bufo viridis)* is more common, which is also able to reproduce in shallow pools. Spade foot Toad *(Pelobates fuscus)*, European Tree Frog *(Hyla arborea)* or Agile Frog *(Rana dalmatina)*, which reproduce in nearby wetlands, occasionally stray into these dry areas too. [7]

Over 70 species of birds occur in these areas, many of them being among the endangered species of the Community interest, such as Hoopoe *(Upupa epops)*, European Nightjar *(Caprimulgus europaeus)* and Woodlark *(Lullula arborea)*. Among the most valuable are the many colored European Bee-eaters *(Merops apiaster)*, resembling flying jewels. They breed in relatively long nest burrows which they dig into vertical loess or sandy walls. Their breeding was recorded for the first time in Záhorie region in 2008 in the abandoned trenches on one of the shooting ranges in Záhorie Military District. Regarding raptor species, the Goshawk *(Accipiter gentilis)*, Eurasian Sparrow hawk *(Accipiter nisus)*, Common Buzzard *(Buteo buteo)* and Honey Buzzard *(Pernis apivorus)* are the most common. Old trees with holes represent an irreplaceable habitat for bats; eleven species have been recorded here. The populations of several game species are also significant, such as Roe Deer *(Capreolus capreolus)*, Red Deer *(Cervus elaphus)* and Wild Boar *(Sus scrofa)*. Black Stork *(Ciconia nigra)* is among the most important bird species of the area. It feeds on fish and amphibians. Both, the European Beaver *(Castor fiber)* and Otter *(Lutra lutra)* can be spotted in the streams and large water bodies, though sightings of otters are quite sporadic compared to beavers. Populations of game animals such as European Roe Deer *(Capreolusc apreolus)*, Red Deer *(Cervusel aphus)* and Wild Boar *(Sus scrofa)* are also important to mention. [1]

Conclusion

At first view, military practice and nature conservation have little in common. Since military areas are less fragmented and benefit from a rather low impact of agriculture and forestry they are of significant importance to conservation. These are often the only remaining sites in our cultural landscape where the establishment of large protected areas seems possible. Most of the military areas, and especially those used for training, contain significant, even spectacular, amounts of natural habitats and landscapes with corresponding abundances of wildlife. They are among the richest and most important sites for biodiversity in Slovakia. Natural values in the MTA are often several times higher than natural values of the surrounding landscape. Therefore, several nature protection projects were performed on the military areas *(LIFE 2006NAT/SK/000115 – Restoration and Management of Sand Dunes Habitats, LIFE 2005NAT/SK/000112 – Restoration of the Wetlands of Záhorie Lowland).* [8]

The end of the Cold War and the expansion of NATO have led to substantial changes in the military sphere since 1990. Military forces have been restructured and reorganized. Because of this, even large sites were taken out of use. Research shows that biodiversity is gradually reduced in these decommissioned military areas. In addition, in those countries which have acceded to the European Union, many military training areas qualified for inclusion in the EU-wide ecological network called Natura 2000. [9]

The knowledge of natural value as well as understanding the importance of their conservation by the military authorities and local people is the best way to gain their support for conservation activity, particularly in military training areas. With the support the military staff it is much easier to ensure the implementation of project activity as well as long-term sustainability of project achievements.

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The Examination of the Economical Effectiveness of Forest Fire Suppression by Using Theoretical Fire Spread Models

Ágoston RESTÁS[1]

It is commonly known that firefighting is very expensive solution; therefore it isn't useless to study it by the criteria of efficiency. But the meaning of efficiency for fire managers can be different from the meaning of efficiency for economists. From an economic viewpoint, it is stricter than from a technical view. Method: this research used geometric aspects of the fire spread created rectangular and concentric circles models and used basic mathematic calculations and logical conclusions. Results and discussion: The rectangular model shows the criteria of economic efficiency of firefighting. Moreover, the results from rectangular model can be transferred also to the section of concentric circles model. Based on the concentric circle model we can define both the economic efficiency of fighting forest fire and minimal criteria of successful suppression expressed by the elementary information we have regarding the actual fire.

Keywords: *firefighting, economic efficiency, rectangular model, concentric circle model*

Introduction

There is difference between the professional and economical effectiveness. Efficiency is obviously stronger phenomena, in this case not just the professional effectiveness but the criteria of the efficiency must be satisfied. [1] No doubt in the sphere of state protection (e.g. medical service, police, disaster management, and fire service) it is very difficult to speak about efficiency, much easier about the political or social effectiveness. However author is sure there are ways to find the balance between useful actions and costs. Fighting against forest fire is usually a long term intervention meaning that it is very expensive; [2] therefore it is not useless to look through some of its economic aspects.

Economic aspects of forest fire were studied by many authors in different ways. One of the oldest studies focused on the annual rate of area burned in Canada and it calculated how to maximize the return of the investment after forest fire. [3] "The clear message from this analysis is that the correct measure of fire's impact is not the burned timber, but rather the reduction in the annual harvest. And the true business of the fire control agencies is the protection of that annual harvest." [3: 9]

Other researchers studied forest fire threatened countries [4] or regions [5] where economic aspects were also involved mostly with "soft" approaches. There are studies where

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economic aspects of fighting against forest fire come from technical parts mainly focusing on details of aerial suppression. [6] [7]

New researches count with the economic impact of forest fires in case of wildland urban interface (WUI) [8] or in this special case even with the costs of health problems. [9]

Because of the high expenditures for aerial suppressions there are many studies focusing on economic view of aerial firefighting. Fogarty [10] made a simple comparison of the cost-effectiveness among the aircrafts used for fire suppression; Pekic [11] suggests new high rate spray technique for making higher effectiveness; Marchi (et al.) [12] made geographical analysis of effectiveness using helicopters for first attack. Author evaluates Gould's works as the most relevant literature in this topic; he has many studies focusing on economic aspects of aerial firefighting. [13] [14] [15]

Author uses geometric way to understand the background of the suppression method better making two models, which are rectangular and concentric circle model, to make it easier to understand some features of the economic aspects of firefighting. Naturally, the assumptions in both models are idealistic, meaning that they require more development.

Rectangular Model

First model examine a forested area limited by rectangular without concrete geometric data. Assumptions are idealistic, like homogenous forest, flat area; there is no wind, etc. In this model the fire front spreads linearly. (Figure 1) Author demonstrates this theory by more rectangulars, placing them next to each other, which shows the fire development by geometric. Some part of this model is similar to the model used by Australian experts however not the same. [13]

After starting the intervention *(B)* the controlled line takes α with the frame of this example edge *(C)*. During the suppression this controlled line will continue till the opposite edge of the frame, meaning that the fire front is extinguished *(D)*. Based on Pythagoras theory it is easy to understand that the value of α depends on the speed of fire spread *(v_{fire})* and the speed of suppression *($v_{suppression}$)*. The higher the speed of suppression related to speed of fire spread *(R)*, the higher the angle α is and vice versa.

$$R\left\langle \frac{v_{fire}}{v_{suppression}} \right\rangle \uparrow\downarrow \Rightarrow \alpha\uparrow\downarrow \tag{2.1}$$

Before the fire front forested area can be saved *(M_{forest})*, beyond it can be counted as damages *(K_{forest})*. The main purpose of the suppression is that the value of saved forest must be as high as possible or the damages must be as low as possible. Author means, we search the end values of the positive options.

$$M_{forest} \Rightarrow max;\ and\ K_{forest} \Rightarrow min \tag{2.2}$$

Above statement can be accepted by the view of professional but since it doesn't count with the cost of extinguishing the result can't be the standard for the view of national economy.

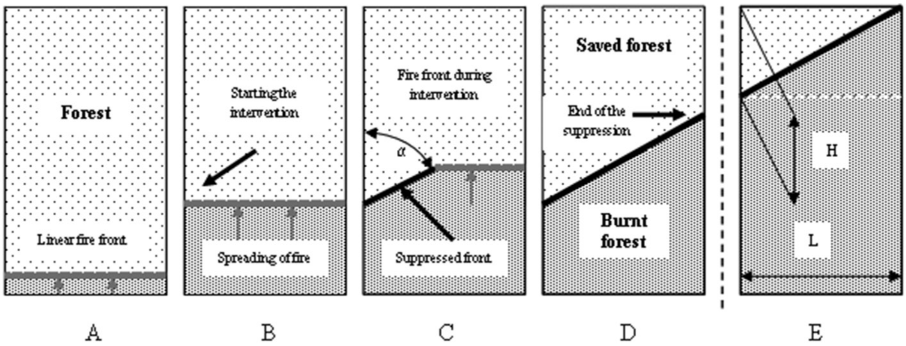

Figure 1. Rectangular model.
(Made by the author.)

To maximize the end value of the professional effectiveness' function can't be justify in all cases at the view of national economy. At the latest one all costs of resources must be counted, such as technical and human resources but even the in-material value of the forest and the higher risk of citizens caused by absence of firefighters from urban area.

If the cost of suppression is higher than the saved forest the action is uneconomical in view of national economy. Looking at the rectangular model the efficiency of national economy is valid till the saved forest is higher than the cost of extinguishing.

$$M_{forest} \geq \Sigma C_{FF} \Rightarrow \gamma_{NE} \geq 1 \tag{2.3}$$

M_{forest} – value of the saved forest (€);
C_{FF} – cost of suppression (€);
γ_{NE} – efficiency of the national economy (–).

Using the notation of the rectangular model the first part of formula (2.3) can be expressed also in another way.

$$\frac{1}{2} LHP_{forest} \geq \Sigma C_{FF} \tag{2.4}$$

L – width of the forest area (m);
H – fire spread from the beginning of the suppression till the end of it (m);
P_{forest} – unit value of the forest (€m^{-2}).

This model doesn't count with the burnt area at the beginning of the suppression, not during the action or at the end of it. In this case the efficiency of the extinguishing in view of national economy doesn't depend directly on the burnt area.

Triangles with L width fire front, α angles and H length in this model are same in any time of beginning the intervention and also same the costs belonging to these triangles.

Based on the rectangular model we get the threshold limit in that case, if the cost of firefighting is equal to the value of the saved forest. In cases of later beginning of the suppression, the cost of firefighting remains the same however the value of the saved forest is reducing continuously till that where remains only the L-α-H featured triangle *(E)*. It means the threshold limit of the efficiency geometrically.

$$\lim_{M_{forest} \to \Sigma C_{FF}} f(M_{forest}) = \Sigma C_{FF} \tag{2.5}$$

In this case, if both the above threshold limit is realized and the efficiency of the firefighting is valid, in any earlier beginning time of the intervention will satisfy the requirements of the efficiency too. The earlier is the beginning of the suppression, the higher the value of the saved forest is. The limit value gives just the minimum threshold of satisfying the criteria of the efficiency.

The angle α of the suppressed fire front depends on the rate of fire spread and the speed of firefighting. Higher fire spread causes lower angle α and longer time of extinguishing and vice versa. In view of higher efficiency the higher angle α is required.

The rectangular model counts with linear fire front however in the reality almost each fire starts from small ignition points. In case of ideal and positive spread conditions the fire front will spread radially.

Necessary but not yet Sufficient Condition for the Efficient Suppression

Model counts with small ignition point, v_{fire} speed of fire spread, t_{freely} time of freely fire spread, but other conditions are ignored. In this case the burnt area A_{fire} (Figure 2 $A_{t1} - A_{t3}$) can be given with the next formula:

$$A_{fire} = (v_{fire} t_{freely})^2 \pi \tag{3.1}$$

Following time units (sec, min, hour) burnt areas form concentric circles. This model got its name of these circles. Distance between the circles depends on the rate of fire spread. The K_{front} fire front can be given by the formula (3.2) and the changing of it is by the formula (3.3).

$$K_{front} = 2\pi v_{fire} t_{freely} \tag{3.2}$$

$$\Delta K_{front} = 2\Delta t v_{fire} \pi \tag{3.3}$$

In the formula (3.3) the extent of the ΔR radiation change can be given by the formula (3.4).

$$\Delta R = v_{fire} \Delta t \tag{3.4}$$

The effectiveness of the intervention can be demonstrated by the length of the extinguished fire section per the time units, that is, the speed of fire front suppression.

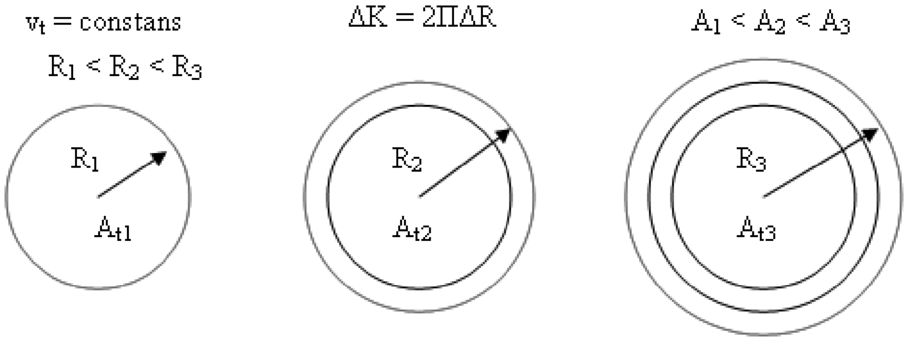

Figure 2. Concentric circles model.
(Made by the author.)

Based on the above for demonstrating the capability of the efforts suppressing fire front author introduce the term of *speed of firefighting (v_{FF})*. It means the length of the fire front suppressed by different resources (human resources, special fire engines, aerial means).

$$v_{FF} = \frac{L_{suppression}}{t_{suppression}} \tag{3.5}$$

v_{FF} – speed of firefighting (ms^{-1}; practically it can be $mmin^{-1}$ or $mhour^{-1}$);
$L_{suppression}$ – length of the suppressed fire front (m);
$t_{suppression}$ – time for suppression (s; practically min, or hour).

To extinguish the fire successfully, the condition must be met that the interveners suppress fire spread. The firefighters have to extinguish the fire front, whose growth per unit of time is equal to the change in perimeter based on the concentric circles model. Thus, the success and effectiveness of the firefighters' work should not be related directly to the speed of fire spread but rather to the change in perimeter! At the beginning of extinguishment, the speed of the extinguishment of fire front, in this case the speed of firefighting with different resources must reach and later exceed the speed of the change of the fire front, that is, the change of the fire front within a given unit of time.

$$L_{suppression} > \Delta K_{front} \tag{3.6}$$

Using the formula (3.6) to extinguish successfully, the next criteria must be satisfied:

$$v_{FF} = \frac{\Delta K_{front}}{t_{suppression}} \text{, or in other form: } v_{FF} t_{suppression} > \Delta K_{front} \tag{3.7}$$

By ordering the above, it becomes clear that in practice the initial condition can be calculated in a simplified way, where we need to take the speed of fire spread multiplied by *2Π*.

$$v_{FF} > 2\pi v_{fire} \tag{3.8}$$

Above in-equality is necessary but not yet sufficient condition for the efficiency of the national economy. Based on mathematical formulas and the logical deductions regarding the concentric circles model author made the following statements:

1. If the speed of extinguishing the fire front – in this case the speed of the firefighting – is below the speed of changing the fire front, the resources are unable to extinguish the fire (initial attack).

2. If the speeds above are identical, the length of fire front will remain but the burnt area will extend (beginning situation; later the balance follow 2πrad).
3. If the speed of extinguishing made by different resources is higher than the increase of the fire front, fire can be suppressed.

Based on the above logical flow we can define both the economic efficiency of firefighting and minimal criteria of successful suppression expressed by the elementary information we have regarding the actual fire. Naturally, the above statements are valid only at the time of beginning the intervention. Later, it modifies as changing the angle of suppressed fire front by the rules of *2***π***rad*.

Results and Discussion: Sufficient Condition for the Efficient Suppression

In the examination of the rectangular model, the conditions of efficient extinguishment in terms of the national economy have already been recorded. Based on them, the extinguishment can be regarded efficient if the amount of the saved value reaches the total costs of the extinguishment. Then, the condition of efficiency is met satisfactorily (2.3). It applies to both the rectangular and the concentric circles model.

One feature of extinguishing forest fires is that regardless of the size of the forest burning, we tend to concentrate on the extinguishment of the fire front, which can be regarded as straight fire line suppression. It can be done or it can be accepted because in case of long-lasting uncontrolled fire spread, the curve of the fire front is hardly perceptible, in practice it can be ignored, so it's linear. If we concentrate on a very small section of fire front, the conclusions of the rectangular model can be applied here, too!

Provided we accept the above statements – the adaptation of the limit values of efficiency set in the rectangular model (2.4) to the very small section of the concentric circles model (3.7) – the formula can be created in the following way:

$$\frac{1}{2}LHp_{forest} \geq \sum C_{FF} \Rightarrow \frac{1}{2}\Delta K v_{fire} t_{suppression} p_{forest} \geq \sum C_{FF}$$

(4.1)

Moreover, the limit value of the efficiency criterion of firefighting out of formula (3.8):

$$2\pi v_{fire} = v_{FF}$$

(3.9)

By reversing the equation and substituting the form pertaining to the actual time of formula (3.3):

$$C_{FF} t_{suppression} \leq \frac{1}{2} 2\pi v_{fire} t_{suppression} v_{fire} t_{suppression} p_{forest}$$

(4.10)

C_{FF} – unit costs of firefighting (average; €h^{-1}; €min^{-1});

$$C_{FF} t_{suppression} \leq \frac{1}{2} 2\pi \left(\frac{v_{FF}}{2\pi}\right)^2 t^2_{suppression} p_{forest}$$

(4.11)

Ordering the above formulas and interpret it to a unit time, that is $t_{suppression} = 1$ min, we can get for the speed of the firefighting the distance of suppression per a minute, that is $v_{FF} = \mathbf{l}_{\mathbf{FF}}\, 1min^{-1}$.

$$l_{FF} \geq \sqrt{\frac{4\pi C_{FF}}{p_{forest}}} \quad (4.12)$$

Based on the above formula we can see that some data are enough for the statement of efficient suppression in view of national economy: as the length of suppressed fire front per unit *(l_{FF})*, the unit cost of average firefighting *(C_{FF})* and the unit costs of forest *(p_{forest})*. Remake the formula and apply it to speed of fire spread:

$$C_{FF} \leq \pi p_{forest} v_{fire}^2 \quad (4.13)$$

It has to take into account that the above values are limit values; by satisfying them aerial firefighting will satisfy the criteria of efficiency in view of national economy too.

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