

Economic System of Evaluating Effectiveness of Fire Protection Taking into Consideration Use of Mobile Robots

Roman Zinko, *Lviv Polytechnic National University*, Jelena Sulojeva, *Riga Technical University*, Boriss Heimans, *Baltic International Academy, Latvia*

Abstract. Rising the level of fire security, reduction of fire risks to socially acceptable level, reduction of the number of the dead and the injures in the result of fire, as well as reduction of damage from fires are achieved applying new technologies, such as mobile fire robots. To assure good results in the scientific research conducted within the framework of this field, the contemporary trends are defined and the relevant research methods are selected. The result of such a research is the creation of experimental prototype of a fire robot.

Keywords: operational efficiency of tracked mover, operative service zone, the economic effectiveness.

I. INTRODUCTION

One of the major priorities in the state security is its fire security. Rising its level, reduction of fire risks to socially acceptable level, reduction of the number of the dead and the injured in the result of fires, as well as reduction of damage from fires are achieved applying new technologies, such as mobile fire robots.

Firemen need robots for delivering fire extinguishing means to the place of ignition in high buildings, for technical inspection of rooms in nuclear power stations, where nuclear reactors are placed, as well as for deactivation of these rooms in the emergency situation.

Modern technologies can manage technical problems, insoluble before, rise the level of fire safety, significantly reduce damage from fire, save water, electric power, cut down capital expenses. Mobile robots can be used for protection of large area territories and of separate outer objects: sports and entertainment complexes, objects of woodworking, oil and chemical industry, oil ports, hangars for airplanes, engine rooms of thermoelectric power stations and nuclear power stations, warehouses of different purpose, as well as flammable objects: reservoir parks of fuels and lubricants, oil cargo piers, heliports, transformer substations.

Fire robots can be divided into mobile and stationary. Automatic fire fighting equipment (AFE) refer to stationary ones and they are considered to be one of the most reliable means of fire fighting: they are activated by objective indices and ensure efficient extinguishing of ignition source on its initial stage without participation of people.

In different states the list of objects subject to AFE protection is regulated by the field normative documents. Presence of automatic fire fighting equipment in fire safety systems of objects is also the requirement of insurance companies to reduce the risk degree.

There are no normative documents elaborated for mobile robots. The reason of it is the novelty of this trend: it is not clear what constructional schemes of these robots are the most effective for fire-fighting, how these robots can be used in emergency situations, what is the economic effect from their use? Research in this field should be started with calculation of economic effectiveness.

II. GENERAL REGULATIONS

Calculation of economic effectiveness of fire protection system is used for performing such kinds of calculations [1]:

- 1) preliminary calculation of economic effectiveness, preparing annual and prospective plans as well as substantiating the variants of new technical solutions in the sphere of fire protection formation;
- 2) calculation of prospective economic effectiveness, fulfilling technical scientific works, as well as on the preparation stage of technical tasks, technical project and workpapers;
- 3) calculation of actual economic effectiveness, introducing the results of scientific research, starting line production of technology, as well as certifying technology to the highest quality degree.

Determination of annual economic effectiveness is based on comparing cut expenses according to the basic value well as to a new technical solution.

While calculating economic effectiveness, the determination of the degree of separate technical parameter improvement influence on economic ratio (value of technology, running operating expenses) is an important moment. The ratio reflecting this coherence is an equivalence ratio.

The equivalence ratio in each kind of technical solution is determined as weighted average arithmetic equation.

As basic ratio for performing economic effectiveness calculations are accepted:

- 1) capital investments;
- 2) cost;
- 3) running operating expenses;
- 4) introduction volume.

Capital investments (C) are reproduction expenses for fixed assets. Determining the annual economic effectiveness for capital investments, all the simultaneous expenses, necessary for creation and application of technical solution are taken into account: direct capital investments into technical solution which define its value, pre-production expenses and

additional capital investments, used in connection with the introduction of technical solution.

Therefore capital investments are included in the structure of State Fire Fighting and Rescue Brigades (further in the text - SFFRB):

- 1) expenses for conducting scientific research, experimental construction and designing, creation and testing of experimental samples, industrial testing that are necessary for verification of results (only in the variant of a new technical solution);
- 2) expenses for purchasing, delivery, assembling, adjustment and acquisition of a new technical solution;
- 3) expenses for modernisation of equipment and making special (non-standard) equipment by enterprise's own forces;
- 4) expenses for supplementing circulation funds, connected with formation and application of a new technical solution;
- 5) value of necessary industrial area and other elements of basic funds connected with formation and application of a new technical solution;
- 6) if a part of replaceable equipment, while introducing new technical solutions, is to be taken down, then the residual value (not including realisation sums) is charged up to capital investments in accordance with a new variant;
- 7) expenses connected with the purchase and delivery of fire-fighting means, whose storage term is longer than a year;
- 8) expenses for other additional works necessary for the introduction of a new technical solution (building new fire-fighting stations and reconstruction of existing stations, building new access roads, etc.).

SFFRB capital investments into formation of new technical solutions are determined according to the formula:

$$K_{vugd} = K_z + K_{r2} \quad (1)$$

Where K_z - expenses for scientific research and experimental construction works, LVL/unit, a year;

K_{r2} - special capital investments into production funds for a new technical solution, LVL a year.

SFFRB current expenses (E) are annual expenses connected with the exploitation of technical solution introduced and they are determined according to formula:

$$I_{vugd} = S_m + S_{da} + S_{kr} + S_e + S_r, \quad (2)$$

Where S_m - expenses for materials, LVL a year;

S_{da} - expenses for salaries, LVL a year;

S_{kr} - expenses for overhaul, LVL a year;

S_e - expenses for technology exploitation, LVL a year;

S_r - expenses for wear of tyres, LVL a year.

Expenses for materials include expenses for fire-fighting means used for fire-fighting and teaching aims.

In economic effectiveness calculations are adjusted according to cut fire protection technology base variant expenses and current expenses.

Performing activities connected with fire-fighters' labour protection improvement, annual economic effect (E) can be calculated according to the following formula:

$$E = \sum_n^{i=1} Z_{ie.m.z.} - (K_{vugd} + I_{vugd}) \quad (3)$$

Where $Z_{ie.m.z.}$ – possible material loss at the objects situated in SFFRB stations service area, Ls, a year;

K_{vugd} – capital investments of SFFRB stations a year, Ls;

I_{vugd} – SFFRB running expenses a year, Ls.

Effectiveness of the use of mobile robots is mentioned in [2-4]. The use of mobile fire robots can serve as an alternative to the AIF. Their functions can be reasonably combined with security system of enterprise. It will decrease financial expenses on exploitation, as well as to use elaborated algorithms of operating. On the first stage of operating of such robots, their main function can be exploring and monitoring the territory in the area where an emergency situation has occurred. In the perspective view – their functions might also include warning and control of people evacuation process in case of fire and self-fire-extinguishing. There is a scheme of reduction of time of searching and beginning of fire extinguishing when using mobile fire robots on Fig.1. In the given case only function of exploring of fire is taken into consideration. Cases when the enterprise is connected to the panel of central observation are examined. Controller announces the signal to the fire-fighting brigade and local brigade of fire extinguishing. The case with using mobile robot reduces time, before starting fire extinguishing. Besides, informational awareness of behaviour of fire is considerably improved because of usage of measuring instruments of robot. Fire robots can be equipped by IR scanners for automatic detection of ignition and TV cameras for video control. Their sensitivity supposes to discover the source of ignition 0,1 m² large within the protected area, but fast-action is a few seconds, during which the size of ignition is defined in three-dimension coordinate system.

Use of mobile robots also increases informational time of fire ensuring (Fig. 2,a). In case of fire brigade starting from fire station, primary information comes from an operator. On their way the head of the brigade reviews the documentation about the object of extinguishing and, upon arrival to the place of fire, he performs examination of the place, survey of eyewitness, as well as reconnaissance.

In case of objects with their own fire brigades or which have the technical means of fire detection installed; dispatchers have more complete objective information about fire. Direct inspection of location of fire is possible (Fig. 2,b). Means of communication being available on the location of fire, dispatcher has the possibility to directly examine the witnesses. Correspondingly, the time of free burning shortens, but the effectiveness of reconnaissance of the source of fire increases.

In case of using mobile robots, the identification of the fire and examination of it are performed simultaneously (Fig. 2,c). Primary means of fire extinguishing being available, immediate localisation of fire is possible. With the help of a robot it is possible to perform monitoring of fire process

during reconnaissance, but during extinguishing robots can be used in the most dangerous places.

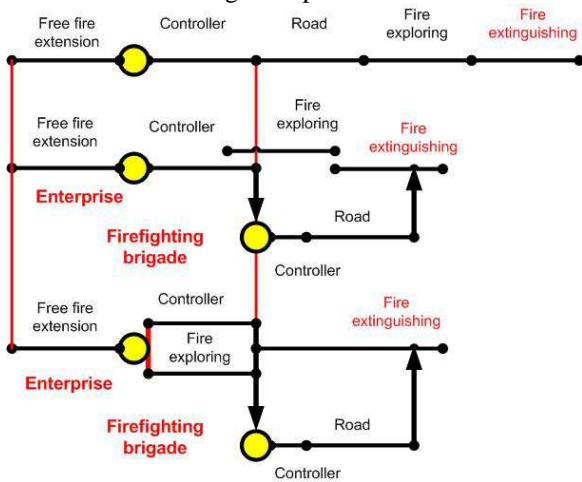


Fig. 1. Reduce of time of fire searching and beginning of fire extinguishing by the use of mobile fire robots.

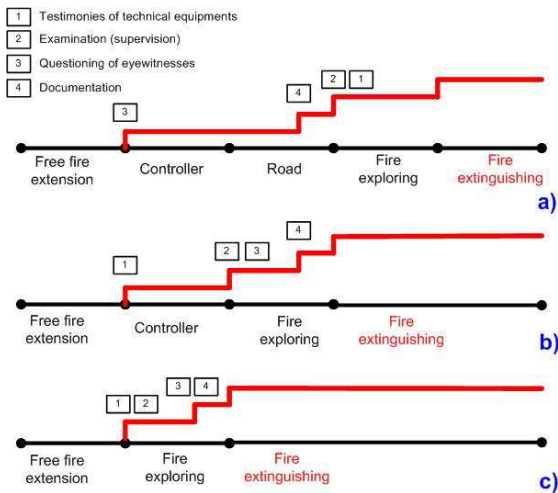


Fig. 2. Reduce of information time of fire searching and beginning of fire extinguishing by the use of mobile fire robots.

Effectiveness of the use of mobile robots depends directly on their constructional perfection and compliance with the conditions of operation. Basically, mobile robots with tracked movers are used in fire-fighting. That is why the research of tracked vehicles and their movers is topical.

Survey and analysis of scientific and technical papers on the functioning of tracked vehicles and patent literature on the construction of their movers gave the following results [5-13]:

1. Theory of tracked mover has been elaborated on the questions of kinematics of inextensible enclosing, rolling of supporting roller on smooth basis, loss of power in a mover and interaction of support path with soil. The problems of durability of tracked mover, dynamics of interaction between tracks with guide and supporting rollers, tractive wheel and steadiness of rim were examined.

At the same time, there is no research of such regimes of movement as robot lodging (its movement with oscillation), undulating movement of sections of disjointed tracked vehicle.

2. Influence of pressure of tracked vehicle on soil and its interconnection with tractive resistance were experimentally

examined. Research of the influence of the construction of a running system on the characteristics of soil and, correspondingly, on cross-country ability is important. But such research has been made not for all widespread variants of construction.

3. The process of load on the base of a track link (track) has been analysed. But no analytic dependence has been presented for design calculations.

4. Presence of tracked vehicle case vibrations that have «track» frequency has been determined. The reason of these vibrations is interaction of track assembly with elements of running system and soil. But mathematic description of this process is absent.

5. For some of the problems discovered a constructive solution on the level of inventions and patents has been offered, but the effectiveness of these elaborations has not been proved.

On the basis of the survey of literary sources connected with improvement of tracked vehicles, the following ways of improving its functioning can also be proposed (Fig. 3).

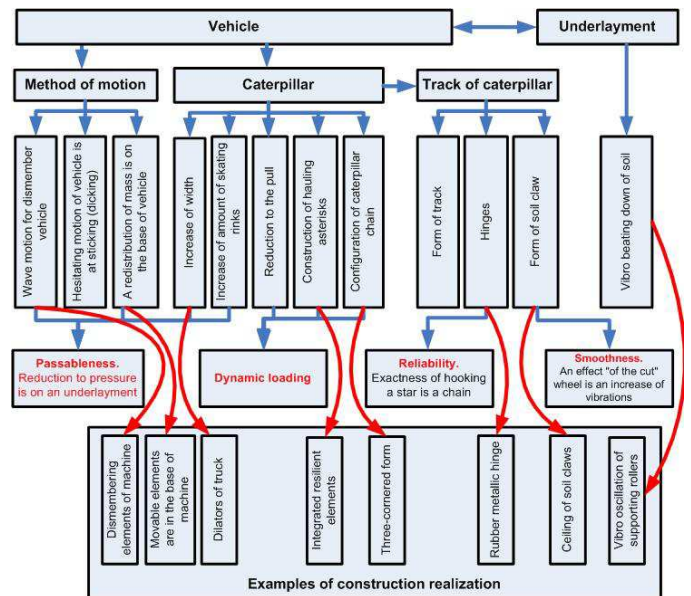


Fig. 3. Possible ways of improving operational efficiency of tracked mover.

The constructive examples can be using modular configuration or multisectionness of a machine. It allows us to effectively use the power of a power plant in transitional movement regimes (acceleration, deceleration) and under hard operation conditions: low bearing capacity of soil, balking. A variant for improving cross-country ability is the use of elastic track expanders. Presence of elasticity increases the effectiveness of the work of a machine. Use of elastic elements in sprockets reduces dynamic load in transmission, improves smoothness of machine motion. Application of rubber steel mounting reduces their wear and improves the precision of interaction of elements „track – traction sprocket”. Overlapping by a grouser of one track and a grouser of the next track allows removing the effect of «faceted wheel», to improve the smoothness of motion, reduce dynamic load on tracked mover. Vibration ramming of soil in tracked vehicle movement gauge raises its possibility.

In Lviv National Polytechnic University experimental prototype of fire robot was created (Fig.4). In the process of robot projecting, the operational and constructive unifications of robot on the bases of its modular construction have been taken into consideration. Structure of system: transport platform with remote control; on board viewing system; system of control and data transfer; panel of the operator with means of control, gathering, saving and processing of the video data.

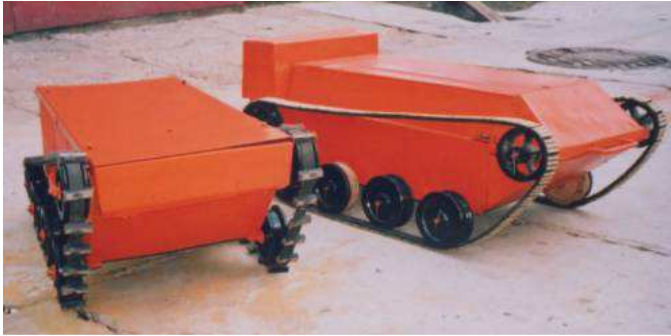


Fig. 4. Experimental prototype of fire robot.

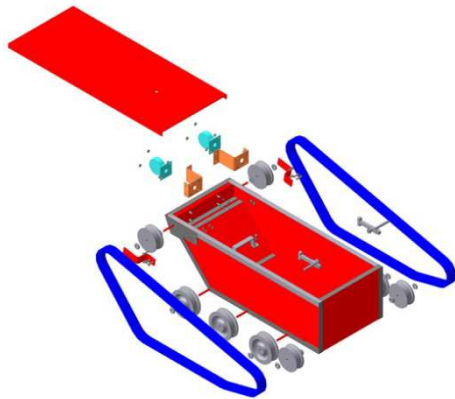


Fig. 5. Construction of experimental prototype of fire robot.

Driving of the robot is provided by caterpillar engine (Fig.5). Gear on the right and left caterpillar is independent. It consists of three-stage reduction gear and direct current motor. The gear supply is made up of automobile accumulator battery. Gear rollers are set at front of the platform, while strain rollers from behind. Such a construction of gear with not a big weight of the platform (36 kl) ensures rather high-speed characteristics (speed of driving up to 1.5 m/s). The basic elements of the transmission are interchangeable. The next step is the elaboration of range of basic elements of the same type. Another peculiarity of creation of prototypes of fire robots was agreement of robot characteristics with conditions, in which they will work, including technical equipment (channels of communication, transfer of video image).

On the prototype of the fire robot the colour-video camera (1/3"; 3.6 mm; 0.5 lux) is set. It transfers data with the help of in-built radio channel. Received video signal is digitized with the help of device USB CAP 100. Received data are after that worked out on the personal computer (in the capacity of which handheld notebook is reasonably used). Control of fire robot is performed on the separate commanding radio channel, radius of action – up to 40m. New software platform of the company

“Electronic systems” – HUNTER –M, is used for the data entry and data processing, as well as for the robot control. The main purpose of which is integration of intellectual means of video surveillance [14].

Algorithms of control with the help of video processing are realized in the software platform – automatic stop before obstacle; setting of the direction of the platform driving with the help of laser marker.

III. CONCLUSIONS

Rising the level of fire security, reduction of fire risks to socially acceptable level, reduction of the number of the dead and the injures in the result of fire, as well as reduction of damage from fires are achieved by using new technologies, such as mobile fire robots.

Effectiveness of the use of mobile fire robots must also consider their economic effectiveness. To increase it, the following calculations are needed:

- 1) preliminary calculation of economic effectiveness, preparing annual and prospective plans as well as substantiating the variants of new technical solutions in the sphere of fire protection formation;
- 2) calculation of prospective economic effectiveness, fulfilling technical scientific works, as well as on the preparation stage of technical tasks, technical project and workpapers;
- 3) calculation of actual economic effectiveness, introducing the results of scientific research, starting line production of technology, as well as certifying technology to the highest quality degree.

To assure good results in scientific research within the framework of the present field, the contemporary trends are defined and the relevant research methods are selected. The result of such a research is creation of an experimental prototype of a fire robot.

REFERENCES

- [1] Sulojeva J. Methods of Evaluation of Fire-Fighting Economic Effectiveness in Latvia. Summary of the doctorate paper. – R.: RTU, 2010. 40p.
- [2] Roman Zinko, Jelena Sulojeva. Usage of robots for the increasing the effectiveness of the fire protection. International scientific conference: 52th Riga Technical University Conference SCEE'2011 “Scientific Conference on Economics and Entrepreneurship” October 7th, 2011, Riga, Latvia.
- [3] Zinko R., Jemeljanovs V., Sulojeva J. Usage of Robots for the Increasing the Effectiveness of the Fire Protection // Scientific Journal of RTU. 15. series., Tehnogēnās vides drošība. – 1. vol. (2011), pp 74-80.
- [4] Зінко Р.В., Сулосва Є.В. Мобільні роботи в системі пожежної охорони // Науковий вісник НЛТУУ: збірник науково-технічних праць. – Львів: НЛТУУ. – 2011, вип.21.17. С.132-138.
- [5] Антонов А.С. Армейские гусеничные машины. Часть 2. – М.: Воениздат, 1973, – 397 с.
- [6] Львов Е.Д. Теория трактора. – М.: Машгиз, 1960. – 252 с. Никитин А.О., Сергеев Л.В. Теория танка. – М: Издание академии БТВ, 1962. – 578 с.
- [8] Гусеничные транспортеры-тягачи. /Под ред. В. Ф. Платонова – М.: Машиностроение, 1978. – 145 с.
- [9] Баженов, С.П. Основы теории гусеничных машин: Учебное пособие / С.П. Баженов. – Липецк: ЛГТУ. 2006. – 278 с
- [10] Вонг Дж. Теория наземных транспортных средств. / Дж. Вонг; пер. с англ. – М.: Машиностроение, 1982. – 284 с.
- [11] Торба А.В. О применении вибрации для повышения проходимости гусеничных транспортных средств по глубокому снегу // Вестник Череповецкого ГУ. – Череповец: ЧГУ. – 2011. – №3.1. С.101-105.

- [12] Кузьо І.В., Зінько Р.В. Моделювання руху розчленованих транспортних засобів. Вібрації в техніці і технологіях. – 2012. – №2(66). – С.42-49.
- [13] Патент 2371345 РФ, МКИ В62D55/24. Трак гусеничної цепи / Коваленко В. А., Давлетова М. А.; – № 2007119344/11; Заявл. 24.05.2007; Опубл. 27.10.2009. – 6 с.
- [14] Шаров Б.В., Маковейчук О.Н., Зінько Р.В. Прототип мобільного охоронного робота з системою технічного зору // Машинознавство. – 2007. – №11(125). – С. 45-47.

Roman Zinko, Candidate of Technical Sciences, Associate Professor, Lviv Polytechnic National University (Ukraine), Institute of Engineering Mechanics and Transport, Department of Mechanics and Automatization of Engineering.
Address: apt.32 LPNU Bandera Street, Lviv, Ukraine
E-mail: rzinko@gmail.com

Jelena Sulojeva, is the assistant manager for study process at the Institute of Occupational Safety and Civil Defence and the lecturer at Riga Technical University. In 2011 she obtained a Degree of Doctor in Economics (Dr.oec.) from Riga Technical University. She was member of the board at SVD Group, Ltd. (2010-2011), the assistant professor and the head of business department at LBK Latvijas Biznesa koledža (2008-2010).
Address: 1/7 - 114 Meza Street, Riga, LV-1048,
e-mail: Jelena.Sulojeva@rtu.lv

Boriss Heimanis, Dr.oec. – obtained in 1992 at Riga Technical University; 1. - Riga Aviation University (1992– 1999) – rector, vice-rector, Head of Department, professor, 2. – the University of Latvia 1999 – 2002 Associate Professor. 3. - Baltic International Academy from 2002 until now. Associate Professor. From 2001 Advisor for High Commissioner of International Roma Union.