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Implementation of Information Technologies in the organization of Forest Fire Suppression Process

Olga Smotr
Department of Project Management, Information Technologies and Telecommunications
Lviv State University of Life Safety
Lviv, Ukraine
olgasmotr@gmail.com

Yuriy Borzov
Department of Project Management, Information Technologies and Telecommunications
Lviv State University of Life Safety
Lviv, Ukraine
uob1968@gmail.com

Nazarii Burak
Department of Project Management, Information Technologies and Telecommunications
Lviv State University of Life Safety
Lviv, Ukraine
nazar.burak@ukr.net

Solomija Ljaskovska
Department of designing and operation of machines
Lviv Polytechnic National University
Lviv, Ukraine
solomiam@gmail.com

***Abstract*— the article deals with information and technical support of the forest fire suppression process. The status update on the problem is considered. The necessity of using modern information decision-making systems in the process of forest fires suppression is substantiated. Improvement of the method of a decision support system constructing using MVC coding patterns is proposed.**

Keywords — information technologies, decision-making systems, MVC coding patterns, organization of the forest fire suppression process.

I. INTRODUCTION

Forest fires are essential natural and anthropogenic factors that excitedly change functions and conditions of the forests. The analysis of the statistical data on the number of forest fires and the area of forests destroyed by fires in the European countries and in Ukraine over the past twenty years has shown that the number of fires as well as the damage caused by them increase gradually [1,2].

The range of urgent tasks aimed at the rapid and effective suppression of forest fires is increasing significantly, and the conditions for their solution are continuously complicated, both by the scale of destructive actions and by various random factors. This requires the development of measures aimed at optimal control of forces and means for the suppression of such fires. This involves such peculiarities of work as operational data collection, analysis and rapid decision-making. The use of information technologies aimed at minimizing the time of managerial decision-making and the cost of its implementation is necessary in such conditions. Implementation of the modern information decision-making systems in the work of the State Emergency Service of Ukraine (SES of Ukraine) gives the possibility to provide rapid and qualitative processing of the incoming information on the nature and characteristics of the forest fire, to predict its parameters and to generate acceptable scenarios for its development. This, in turn, allows the forest fireground commander (FFC) to make scientifically-substantiated and effective management decisions for its suppression.

The world practice of effective management in various sectors, including control in emergency situations [3-6], proves the need for application of informational decision-making systems (DMS), in which the knowledge and experience of specialists working in the relevant spheres of human activity are used.

Today, the departments of the State Emergency Service of Ukraine use the "Government Information and Analytical System for the Suppression of Emergencies" (GIASSE) to solve operational and tactical tasks. In particular, in the Lviv region, the Supervisory Control And Data Acquisition (SCADA), the territorial subsystem of the GIASSE [7], is used.

II. PROBLEM STATEMEN

However, the Supervisory Control and Data Acquisition do not solve such tasks as:

- evaluating of the potential for emergency response throughout the region;
- modelling of forest fire spread;
- generating, analysis and selection of the best fire-fighting tactics, taking into account the operational environment, technical capabilities and resource constraints;
- visualisation of the chosen scenario;
- support of the chosen scenario implementation in real time mode with the possibility of its correction due to changes in the operational environment.

SCADA is mainly intended for supervisory monitoring and does not help the forest fireground commander to make a decision.

The above circumstances determine the need for further improvement of the existing and implementation of new modern information DMS in the operational activities of SES of Ukraine.

According to the main provisions of the general management theory, managing forces and means during the

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forest fires suppression can be considered in time as the functioning of supervisory control system. In particular, it can be represented as a dynamic system [8] (Fig. 1), where: the input parameters P_i are determined by terrain features, forest vegetation, etc.; perturbing actions P_j – weather conditions (speed and direction of wind, humidity, etc.); ΔP_i, ΔP_j - leading factors, the values of which depend on the parameters of the purpose of fireground command and control C_k; O_l – set of output parameters (forest fire area, its intensity and rate of fire spread, etc.). All these conditions can vary: topographic - in space, weather - in space and in time, the purpose of fireground command and control depends on the strategy and tactics of forest fire suppression. The values of the leading factors (actions) depend on the intensity of the forest fire spread and the efforts made to eliminate it. The dynamics of forest fires and their suppression is usually rapid, and meteorological conditions are often unpredictable. The information on the conditions of the forest fire is usually incomplete, uncertain and, in some cases, erroneous, which complicates the process of its suppression. The human factor (e.g. professional training and skills) and the material base of fire and rescue units are also important, because these factors effect on the speed of the forest fire suppression.

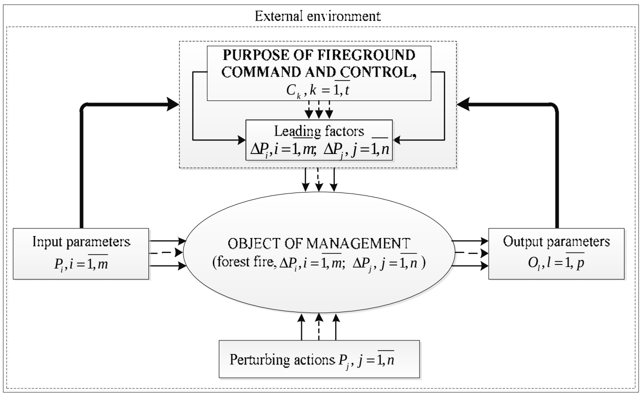


Fig. 1. Management of a dynamic forest fire suppression system

In this context, the decision-making process, that deals with the strategy of forest fire suppression, in its essence, is identified with the activities of the decision maker, that is, the forest fireground commander.

When operating fire-rescue units (FRU), DMS-based activities of the forest fireground commander can be shown by using such block diagrams (Fig. 2), on which it is possible to study the main stages of the management decision-making process.

Obviously, modelling the current state of the control object (forest fire), generating a set of variants of its interaction with the objects of action (FRU's forces and means), predicting the expected effects of the decisions, etc. are impossible without prompt and qualitative modelling of the forest fire behavior.

III. The Proposed Method Of Constructing A Decision-Making System In Organizing The Forest Fire Suppression Process

To simulate the forest fire behaviour, a scheme based on classic Model-View-Controller coding patterns [9, 10] is widely used nowadays. Tt consists of three levels:

- Model level – Provides data (usually for view), and responds to queries (usually from the controller), changing its status;
- View level – is responsible for displaying both the input information and the information obtained during the process of modelling (user interface);
- Controller level - interprets data entered by the user and informs the model about the need for the corresponding response (control logic).

The improved structure of the decision-making system for forest fire elimination is shown in Fig. 3

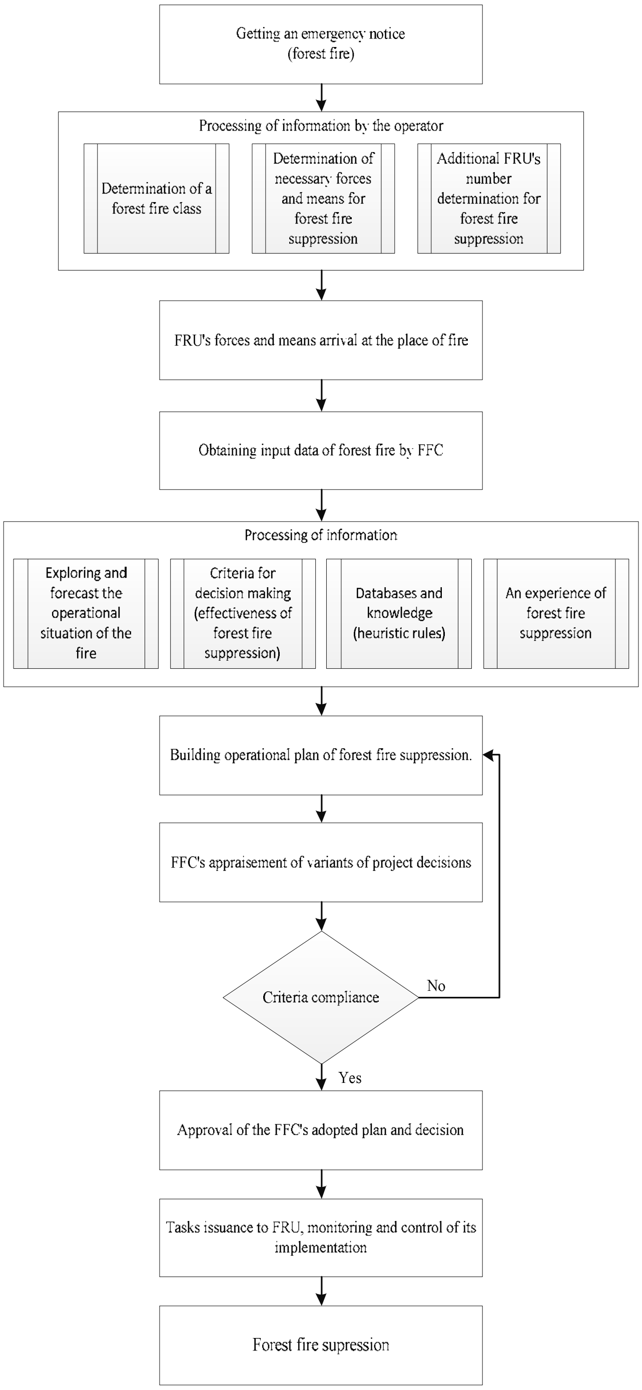


Fig. 2. FFC's activities

In such scheme, both View and Controller levels are directly dependent on the Model level, but the Model level does not depend either on the View or on the Controller. This is one of the key benefits of this delineation, which allows building a control object model regardless of its visual representation, as well as creating several different views for one model.

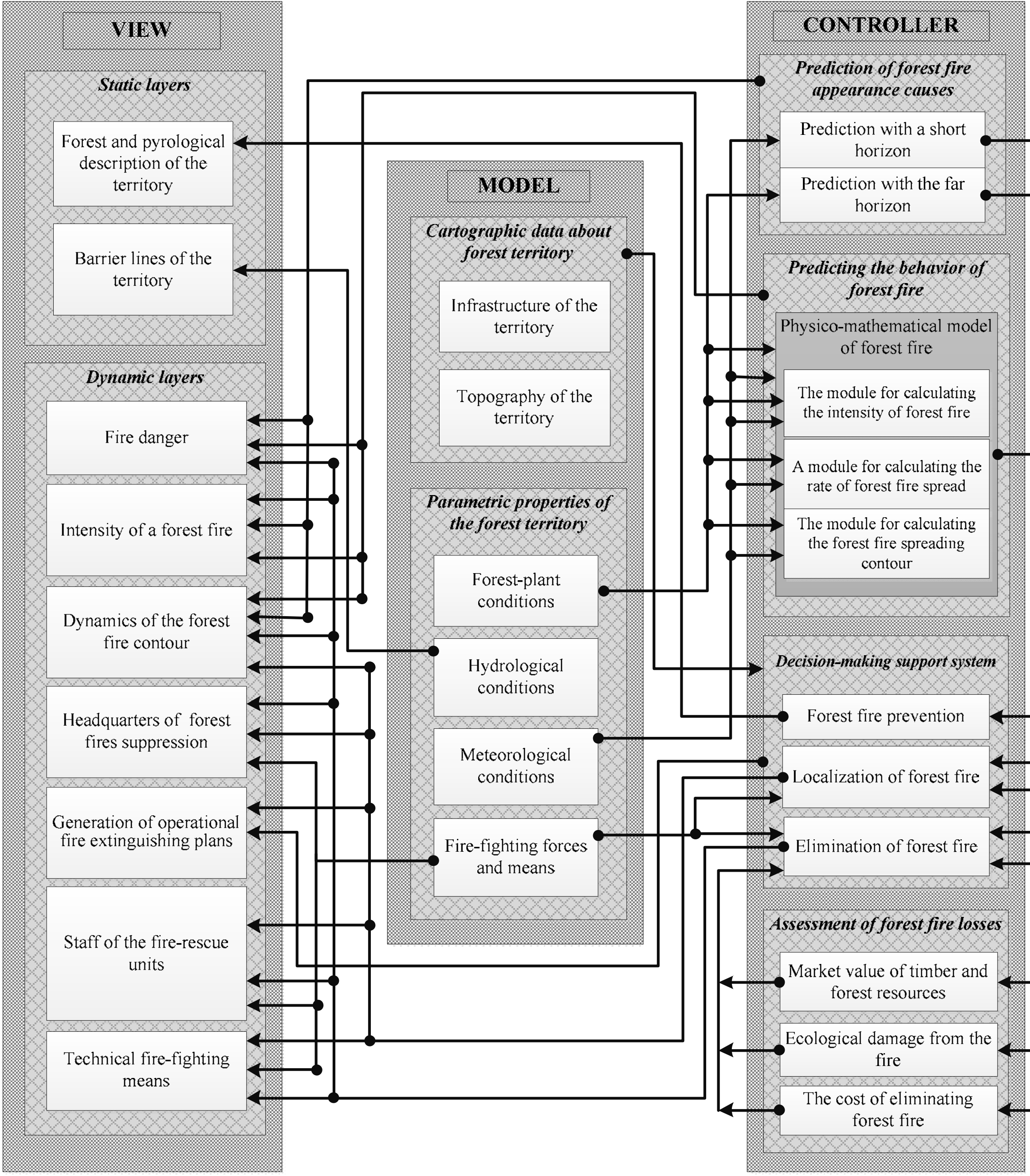


Fig. 3. Structure of the decision-making system for forest fire elimination (based on [11])

The View level of the MVC scheme is an electronic map of the forest area given to the forest fireground commander for a visual familiarization with its features. The map has a layered structure and consists of the main (static) and additional (dynamic) layers. Static layers usually reflect forest vegetation and pyrological characteristics of forest areas that may be subject to fires. Such layers include forest areas (which represent layers of deciduous and coniferous species, young stands or litter, etc.), soils, water bodies (showing lakes, swamps, rivers, etc.), access roads and routs (the type of road surface, width, height/descent are taken into account), etc. Dynamic layers display data that undergoes pre-processing at the Controller level. These are layers such as a mapping scheme for the distribution of fire danger (pre-calculated in the forecasting block for the reasons for the occurrence of a forest fire), forest fire behaviour (determined in the block of forest fire spread forecasting), and decision-making systems. In addition, the forest fire command center, the personnel of the fire and rescue units, as well as the location of fire extinguishing equipment (the number and composition of which are also determined in the appropriate block) are displayed visually on the dynamic layer.

The Model is one of the three components of the MVC coding pattern that describes the state of spatial data at the time of the forest fire detection. It consists of two interrelated parts – cartographic and attributive. Cartographic data describes the positional characteristics of terrain (topography and infrastructure of vector objects). Attributive data gives the characteristics of vector objects – the dynamics of forces and means transfer, as well as meteorological and hydrological conditions.

The logical part of MVC coding pattern (Controller level) consists of three main blocks, each of which is aimed at solving one of the tasks:

- prediction of forest fire spread;
- assessment of fire losses;
- decision-making system for forest fires preventing and suppression.

We offer to add the fourth block to the list of tasks that are solved by the MVC controller: analysis of the causes of forest fires and calculation of burning index class. This will give an opportunity to evaluate the preparedness of forest vegetation areas for combustion and predict fire risk. At the same time, we offer to implement two options for predicting the causes of forest fires. The first of these is prediction with a short horizon and is used in the development of operational tactics for the forest fire suppression. The second – with the far horizon (used for prediction of the causes of forest fires and development of a strategy for their prevention).

Considered above proposed method of constructing a decision-making system in organizing the forest fire suppression process makes it possible not only to model fire behaviour but also to calculate fire risks for taking preventive measures.

IV. PRACTICAL SOLUTION OF FOREST FIRE BEHAVIOUR PREDICTION PROBLEM

An important stage in development of conceptual strategies and choosing effective forest fire suppression tactics is prediction of forest fire global characteristics. They are determined by the influence of its main factors on the spreading geometry at any given time.

When developing the process of forest fire liquidation management strategy is necessary to anticipate and take into account the dangerous tendencies of its further development and also potential threats to settlements and security objects. Therefore, such prediction is extremely important.

Calculation of the probable forest fire spread rate and the intensity of the heat production during combustion process is made within a defined stage of time prediction: first in the direction of spreading the front of the fire, then the flanks and the rear. We used an empirical formula for prediction the speed of fire limit spread on each forest section. This formula contains variable coefficients of relative influence of various factors, namely:

$$\tilde{V}^{\mathrm{h}}(\alpha_{\nabla},\omega_a,\upsilon_c)=\left\{V_i^{\mathrm{h}}(\alpha_{\nabla},\omega_a,\upsilon_c)=V_0(r_n,p_{\kappa},u_{в})K_i(\alpha_{\nabla})K_i(\omega_a)K_i^{\mathrm{h}}(\upsilon_c), i=\overline{1,N^{\mathrm{d}}}\right\} \quad (1)$$

where $V_0 = V_0(r_n, p_{\kappa}, u_{в})$ – basic (calm) rate of fire spread, m/min; r_n – type of forest vegetation specified in the area's pyrological description; p_{κ} – complex meteorological fire danger index at the time of fire appearance; $u_{в}$ – conditions for drying of forest vegetation in area; $K_i(\alpha_{\nabla})$, $K_i(\omega_a)$, $K_i^{\mathrm{h}}(\upsilon_c)$ – coefficients of influence on the rate of fire spread in accordance with the terrain inclination α_{∇}, relative air humidity ω_a and wind speed υ_c; N^{d} – number of forest areas; index 'h' defines wind direction $\mathrm{h} \in \{\mathrm{fr}, \mathrm{fl}, \mathrm{r}\}$: fr – frontal, fl – flank, r – rear.

For all coefficients of influence with using the method of least squares approximation of experimental data empirical dependencies were obtained for next calculation of their values.

Coefficient of the terrain inclination influence $K_i(\alpha_{\nabla})$ at i – forest area, specified in area's pyrological description of forest vegetation. It depends on magnitude of the angle α_{∇} and slope exposure towards the sides of horizon and direction of combustion process spreading (up the slope – angles are positive, down – are negative, across the slope – zero):

$$K(\alpha_{\nabla}) = 0,0142e^{0,1635\alpha_{\nabla}} + 1,0776e^{0,0169\alpha_{\nabla}} . \quad (2)$$

The value of relative air humidity influence coefficient $K_i(\omega_a)$ on i -area of forest should correspond to the value predicted its relative humidity $\omega_a = \omega_a(t)$ during the course of fire at t - moment of its occurrence.

$$K(\omega_a) = 2,028e^{-0,0898\omega_a} + 1,9982e^{-0,0186\omega_a} . \quad (3)$$

Coefficient of wind power impact $K_i^{\mathrm{h}}(\upsilon_c)$ on i – forest area is determined using quadratic form that based on speed υ_c and wind direction relative to the spread of fire:

$$K^{\mathrm{h}}(\upsilon_c) = 1,0 + \begin{pmatrix} 0,17877 \\ 0,16192 \\ 0,03659 \end{pmatrix} \upsilon_c + \begin{pmatrix} 0,32705 \\ 0,10822 \\ 0,02609 \end{pmatrix} \upsilon_c^2 : \ \mathrm{h} \in \{\mathrm{fr}, \mathrm{fl}, \mathrm{r}\}, \quad (4)$$

where $K^{\mathrm{h}}(\upsilon_c) = (K^{\mathrm{fr}}(\upsilon_c), K^{\mathrm{fl}}(\upsilon_c), K^{\mathrm{r}}(\upsilon_c))$.

Wind speed υ_c under the forest mass is normalized by the following formula:

$$\upsilon_c(\upsilon_{м}, p_d) = \upsilon_{м} K_d(p_d), \quad (5)$$

where $\upsilon_{м}$ – wind speed according to the weather station, m/s; $K_d(p_d)$ – coefficient of normalising to the fullness of the tree p_d, which is determined by the ternary algebraic form.

$$K_d(p_d) = 0,7818 - 0,9452p_d - 0,2527p_d^2 + 0,46995p_d^3 . \quad (6)$$

Calculation of the values for each forest area and each tactical part of the forest fire is carried out by the end of the first stage of prediction. For determining saturation point of last section we should take into account the duration of fire spreading to this area, namely:

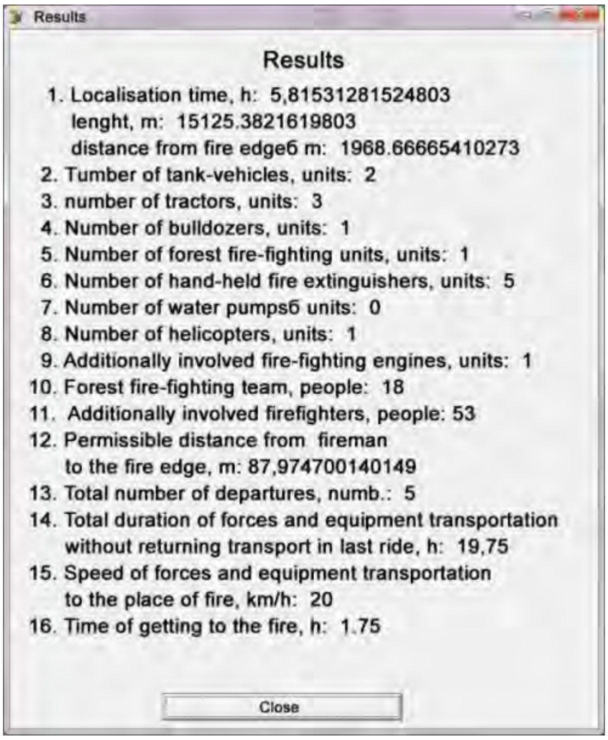
$$L_i^{\mathrm{h}} = V_i^{\mathrm{h}}(\ldots) \cdot (t_i' - t_{i-1}'),\ i = N^{\mathrm{d}} : \mathrm{h} \in \{\mathrm{fr}, \mathrm{fl}, \mathrm{r}\}, \quad (7)$$

where L_i^{h} – the distance that the edge of fire must pass on $i = N^{\mathrm{d}}$ section to the end of determined forecasting stage, m; $V_i^{\mathrm{h}}(\ldots)$ – speed of fire spread on the area in the last sector, m/min; t' – time of the forecasting stage completion, min; t'_{i-1} – time of the fire spread completion in penultimate section, min.

For confirmation of formulas (3) and (4) was conducted full-factorial experiment of determining actual forest fires spread speed. The relative error of calculated fire spread rate by dependence (1) in relation to the actual value which was obtained experimentally, is by about 5.5%. This value of the error indicates that the simulation results which are obtained on the basis of observational statistical data processing are close to the actual ones. Similar researches were conducted for predicting the intensity of fire heat release at its boundaries, for computing speeds of fire perimeter increase, which depends on the speed of fire frontal edge spread, and for determining forests soot height.

The developed mathematical models of forest fire spread dynamics allow us to determine the speed of forest fires edge spreading and to predict the intensity of heat release from it. All calculations depend on the characteristics of main combustion conductor's types and complex meteorological indicator of fire hazard.

Practical calculations of forest fires edge spread speed and predicting the intensity of heat release were performed in special software. This software uses detailed maps of forest vegetation and weather forecast data. This makes it possible to take into account dangerous trends in forest fire spreading and to develop a strategy for its elimination. Also it helps to determine methods of stopping and calculating the necessary amount of forces and means for eliminating the fire (see Fig.4.)



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Results
 1. Localisation time, h:  5,81531281524803
    lenght, m:  15125.3821619803
    distance from fire edge6 m:  1968.66665410273
 2. Tumber of tank-vehicles, units:  2
 3. number of tractors, units:  3
 4. Number of bulldozers, units:  1
 5. Number of forest fire-fighting units, units:  1
 6. Number of hand-held fire extinguishers, units:  5
 7. Number of water pumps6 units:  0
 8. Number of helicopters, units:  1
 9. Additionally involved fire-fighting engines, units:  1
10. Forest fire-fighting team, people:  18
11.  Additionally involved firefighters, people: 53
12. Permissible distance from  fireman
    to the fire edge, m: 87,974700140149
13. Total number of departures, numb.:  5
14. Total duration of forces and equipment transportation
    without returning transport in last ride, h:  19,75
15. Speed of forces and equipment transportation
    to the place of fire, km/h:  20
16. Time of getting to the fire, h:  1.75
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Fig. 4. Optimal amount of means and forces for the forest fire elimination calculated in program

V. CONCLUSION

Forest fireground commander in emergency situation has to make operational decisions in such conditions: incompleteness, unreliability, inaccuracy of incoming information, rapid flow of events, limited time for a comprehensive analysis of the situation, a significant number of participants involved in the forest fire suppression process, etc. Therefore, probability of making an effective decision without the use of decision-making systems is rather low. In order to reduce the probability of wrong choice in determining the forest fire suppression strategy, and to reduce the time for making management decisions, the FCC must apply proper decision-making systems that accurately describe the processes occurring during the forest fires and are use the special knowledge of the best specialists with extensive experience in this field. Unfortunately, despite the significant number of existing decision-making systems, today the SES of Ukraine does not have effective decision-making systems suitable directly for the forest fireground commanders.

One of the ways used for improvement of such systems is introducing MVC coding patterns. Such patterns enable not only to model the forest fire behaviour but also to calculate fire risks and to assess the material, environmental and socio-organizational consequences of potential fires in order to taking for taking preventive measures.

REFERENCES

[1] National report on the state of technogenic and natural safety in Ukraine, 2017. Retrieved fromwww.dsns.gov.ua/files/2017/8/18/Analit%20dopovid/2%20statistic.pdf.

[2] Official web-page of National Interagency Fire Center (USA). Retrieved from www.nifc.gov.

[3] S. D. Bushuyev, N. S. Bushueva, I. A. Babaev, et al., Creative technologies in managing projects and program. Kiev: Summit Book. 2010.

[4] V. Titova, "Informational and analytical decision support for operational duty services," Artificial intelligence, no. 4, pp. 504-509, 2006.

[5] C. W. Holsapple, and A. B. Whinston, Decision Support Systems: A Knowledge-Based Approach. West St. Paul, MN, 1996. Retrieved fromhttp://www.uky.edu/BusinesEconomics/dssakba/insmat.htm.

[6] O. O. Smotr, "Use of information systems to support decision-making in management of fire and rescue units of the Emergency Ministry of Ukraine," In The problems of information technologies application, special technical means in the activity of executive authorities, educational process, interaction with other services, Lviv: Lviv State University of Internal Affairs, pp. 270-273, 2011

[7] Official web-pageof The State Emergency Service of Ukraine in Lviv region. Retrieved fromhttp://lviv.dsns.gov.ua/ua/Sistema-operativno-dispetcherskogo-upravlinnya-SODU.html.

[8] G. A. Dorrer, Mathematical models of forest fire dynamics. Moscow: Forest industry, 1979.

[9] G. D. Glavatsky, and V. M. Grumans, "Information model and tasks of optimizing the process for forest fires combating," Forestry, no.1, pp. 36-41. 2002

[10] V. E. Khodakov, and M. V. Zharikova, "Architecture of information technology for decision support for prevention and suppression of forest fires," Problems of Information Technology. no. 02(006), pp.116-122. 2009.

[11] O. O. Smotr, and Yu. I. Grytsyuk, "Models and methods of management of extinguishing forest fires," Bulletin of the Lviv State University of Life Safety, no. 5, pp. 123-129, 2011.