Support for decision-making to combat natural fires in Taiga-Analyst system

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Abstract. The system of regulatory documents defining the processes of decision-making on combating natural fires in the Russian Federation is described and the necessity of creating an information system to support decision-making in this field is justified. The processes of detection and response to natural fires are presented in the form of agency models. The structure of the system of support of decision-making on the use of resources and means for fire elimination, based on the software product "Taiga - Analyst," is proposed. The system is implemented on the basis of agency simulation modelling and allows to select forces and means for fire control, model its propagation and elimination with reference to the terrain map using a geographic information system. The scheme of decision-making in the fight against natural fires using the proposed system is shown. Participants of fire fighting as agents from the moment of fire detection to the moment of use of forces and means are considered in detail. A comparative analysis is presented with an indication of the technical characteristics of aircraft involved in the fight against natural fires.

1. Introduction

Natural fires, as dangerous and dynamic processes on the surface of the Earth, which are usually accidental in time and space, often in difficult places, are a complex object in terms of monitoring and modelling. However, effective control of them is impossible without prediction, which is based on the use of adequate mathematical models describing their behavior. It has been shown that one of the significant causes of large and mass forest fires threatening human settlements, life and health is the lack of reliable short-term forecasts of their development at the forest-settlement border. Effective prediction of forest fire hazards requires the availability of mathematical, programmatic and information support for the management decision-making process. To date, a large number of mathematical models has been created, describing the process of distribution of natural fires, their overview is contained in the works [1-11].

Work is also under way to establish systems for managing natural fires [12-27]. In such systems it is necessary to combine fire propagation modeling and fire fighting forces and means. Given the large number of active participants in this process, it is useful to use the agency modeling methodology to create management systems.
The authors developed a prototype system "Taiga - Analyst," based on multi-agent modeling. The system allows modeling both the process of natural fire propagation and interaction of fire with forces and means for its elimination, which perform direct fire edge suppression. At the same time, a number of important objects also involved in fire fighting are not considered or described schematically.

The purpose of this work is to expand the capabilities of the Taiga-Analyst system by introducing and describing in more detail the agents that model previously not described forces and means of fighting natural fires. In particular, it is of interest to develop agents that simulate the operation of ground fire-fighting equipment and tools, such as bulldozers, forest ploughs, motor pumps, blowers, as well as aircraft (fixed-wing aircraft and helicopters) using drain devices. All these funds should be used in the frame of the unified state system for disaster management (hereinafter referred to as RSF), which is briefly described below.

2. Russian emergency response system

At present, the Russian Federation has established a unified State system for the prevention and elimination of the consequences of emergencies (hereinafter referred to as the RSF), one of the tasks of which is to organize and coordinate the actions of the forces and means involved in the fight against natural fires. The RSF is a complex hierarchical structure incorporating controls, forces and means of 45 functional subsystems under the authority of 21 ministries.

The Ministry of Natural Resources and Ecology of the Russian Federation, represented by the Federal Forestry Agency "Rosleskhоз" (hereinafter - FALH), is directly responsible for extinguishing natural fires by Order of the Government of the Russian Federation No. 146-R of 06.02.2003 "On improving the organization of work on protection of forests from fires."

In the event that the forces or means of FALH are insufficient to locate and eliminate a natural fire or one of the criteria for an emergency forest fire situation is met, the Commission for Disaster Management and Fire Safety at the appropriate level of response (hereinafter referred to as the CC) is convened. The tasks of ERC are to determine the necessity of proclaiming high-readiness and emergency states.

The fundamental difference between these two emergency states is that in the first mode, when there is only a threat of emergency, there is a strengthening of control over the situation, formation of operational groups and organizations, their nomination to the expected areas of operation and evacuation, i.e., and in case of declaration of the emergency regime, when the emergency situation has already occurred, measures to localize the natural fire and eliminate the consequences are added.

KChS are created at the federal, regional, municipal, object levels and formed of structure to Universal State System of Prevention and Response to ES (RSChS) which functions and purpose are defined by the government resolution of 30.12.2003 No. 794 "About Universal State System of Prevention and Response to ES".

The control of the actions of the forces and means of the RSF in case of threat and occurrence of emergency situations from natural fires is carried out using a decision-making support system (RPS), including control information systems, as well as databases and knowledge.

It is defined that the process of extinguishing a natural fire should begin from the moment of its detection. The spread of the fire is influenced by factors such as weather conditions, terrain, type of plant combustible material and others. The decision-maker (LPR) receives information on the presence of the fire and its characteristics during time t1 by obtaining space monitoring data, from observer pilots, from a foot reconnaissance team.

The next step is the process of expert evaluation of the received fire information and background information on the factors affecting the process. As a result of information processing during time t2, the LPR gives an indication of the use of forces and means taking into account the considered factors. Tactical solutions are influenced by the following factors: availability of water sources and their distance, weather and climatic conditions, availability of infrastructure facilities, including roads, concentration of forces and means, their distance from protection facilities and from fire source, forest management of the territory.
These factors influence the time of concentration and introduction of forces and means to extinguish fire $t_3$. Further, the process of obtaining information on fire during time $t_1$, analysis of information on fire process impact results and decisions on further increase of forces and means or their adequacy are repeated (figure 1).

$$\Delta t = \sum t_1 + t_2 + t_3 + t_{lpr} \quad (1)$$

3. Structure of Taiga-Analyst Decision Support System

In order to assist the expert in choosing the right solution, information and control systems, which include the Taiga-Analyst system (URL: http://u702972.s15.wh1.su/), are important for simulating forest fire situations on the map of real terrain and simulating fire dynamics under the influence of measures to extinguish it using a geographic information system (GIS).

The software basis of this system is the agency-oriented simulation system "Taiga-3", the distinctive feature of which is the possibility of modeling the dynamics of both freely propagating fire and fire under the influence of fire forces. In addition, the Taiga-3 system contains reference normative databases.

The first stage of the Taiga-Analyst system created to date can take into account the following factors:

- Wind speed and direction, altitude, terrain, temperature, pressure and precipitation,
- Geolocation binding (latitude, longitude),
- Availability of linear, area and point objects (oil pipelines, roads, engineering facilities),
- Distance from water sources, settlements, their size and population density,
- Presence and location of the responding units with indication of available forces and facilities,
- Classes of weather and natural fire hazards,
- Operating thermal points and their characteristics.

When using the Taiga-Analyst system, the decision algorithm is corrected as compared to Figure 1 and looks as follows (figure 2):
Figure 2. Decision diagram for detection and response to natural fires.

where, \( t_v \) - interaction time, \( v = 1,2,3 \); - factors affecting the process; TCL - time for analysis, calculation, check, selection, \( \cdots \) arrows mean data transfer processes.

In the base of SPPR "Taiga-Analyst" data characterizing constant parameters of the system are already stored, it is necessary to enter only variable data (weather conditions, coordinates of thermal points) and model fire propagation using measures to extinguish it. The Taiga - the Analyst system is capable to carry out modeling as freely developing fire, and the fire which is under the influence of the constructed fire-prevention barriers, people - firemen and dumping of water by the aircraft (the plane, the helicopter). Using this system, the task of the SCL is simplified and reduced to choosing the method of use of forces and means, resulting in significantly reduced decision time. Time of decision-making consists of the sum of times spent for cycles \( t_1, t_2, t_3 \) and \( t_{lpr} \) where \( t_{lpr} \) is time necessary for the analysis of a situation, the choice of a way of actions. At that, time of fire parameters change observation \( t_1 \) is corrected in \( t' \), -time of fire parameters change observation (figure 2).

The Taiga-3 system uses four types of agents: combustion front elements (Type A agents), forces directly affecting the process to localize it (Type B agents), forces and means indirectly affecting the dynamic process by changing the characteristics of the medium (Type D agents), and finally Agent Manager (Agent M).

In practice, however, significantly more types of agents are required to adequately describe the fire control process. For example, forces that directly influence the process but have different technical and tactical characteristics should be considered separately.

With the Taiga-Analyst system, the control of the extinguishing process can be schematically represented as a diagram in Figure 3, where Type A agents form a fire loop that can be modified - increased or decreased. It depends on the characteristics of plant combustible material, wind speed, pressure, precipitation, terrain and its exposure to agents. Let’s take a quick look at their purpose.

4. **Agents used in the Taiga-Analyst system**

The K1 Agent is a base of aviation and ground forest protection, and includes decision makers as well as administrative functions. The operation time of this agent depends on the time required to receive a command from Agent O to decide the amount of equipment used, determine the source and method of delivery of the equipment to the location of the fire site and issue an instruction to the personnel involved.

Agent K2 - functional subsystems of RSF (MES, MO, MIA), which are part of CSF. The time of their operation depends on the time of receipt of the command for readiness, advance and
maneuvering of forces and means, which are determined by agents of type I, F, E specified in the "Plan of measures for prevention and elimination of emergency situations during the occurrence of natural fires in the territory of the subject of the Russian Federation."

Figure 3. Diagram of interaction of "Taiga-Analyst" system agents during detection and extinguishing of natural fires.

The K3 agents are personnel from the Federal Forestry Reserve, which provide fire fighting work to the state's E1 forest firefighters - agents of the state. The time of their operation depends on the time of receipt of information, determination of sources of formation of teams of forest firefighters, choice of their delivery method and return of indication for nomination.

K4 agents are tenants, i.e. persons who provide equipment and specially trained people for fire fighting, or who allocate money for it. The allocation of people and equipment is carried out in accordance with the consolidated fire fighting plan.

Agents of B1 are the persons which are carrying out patrol along the approved route within aviation monitoring, frequency of patrol depends on a class of weather fire hazard and varies from 2 times a day or 1 time in 3 days.

Agents B2 are observer pilots transmitting information from the vessel via Agent B3 Air Navigation Dispatcher to RDS Agent D.

Agent F is a helicopter. It is used for unloading paratroopers - firefighters, delivery of equipment to the emergency zone, discharge of water using a water drain device (BCY5, VSU15). Helicopters with
the possibility of conversion from cargo and passenger to firefighter are a separate value. For example, Mi-26TP is designed to extinguish fires, including industrial ones, in all physical and geographical areas, delivery of special equipment and landing. Water discharge is performed in 35-45 s, filling on the ground - not more than 2 min. Conversion of transport Mi-26T to fire Mi-26TP takes not more than an hour.

Agent I is a plane. It carries out the following actions: gets the command to take off, takes off, produces water intake, arrives in the emergency zone, detects fire, aims, drops water, unloads equipment or people with landing, falls from the emergency zone. On purpose these agents are divided into two views: planes for delivery of task force of rescuers, physicians, special equipment, machinery and equipment and planes for discharge of water from air. Depending on the brand and configuration, agents are characterized by various tactical and technical indicators, including fuel consumption. Like helicopters, some aircraft models can be multifunctional. For example, four people, using mobile telfers on the ceiling part of the aircraft, are able to load and ВАП-2 the pouring aircraft device in about 1.5-2 hours. The standard IL-76 aircraft can be converted to IL-76TDP within 4 hours.

Preparation for fire-fighting flights with the use of pouring aircraft ВАП-2 instruments is determined by the time of aircraft fuelling with fuel and water into two tanks. At centralized filling and optimal water pressure in the hydraulic system, preparation does not exceed 15 minutes. If there is no centralized filling with water, filling using fire vehicles is possible (table 1).

| Type       | AH-32П | БЕ-200ЧС | МИ-8МТВ | МИ-26 | ИЛ-76П | ИЛ-76ТД | ИЛ-76ТДП | Bombardier CL-415 | Ан-74П |
|------------|--------|----------|---------|-------|-------|-------|-------|-------------------|--------|
| Max speed, km/h | 530    | 710      | 250     | 295   | 850   | 800   | 860   | 359               | 720    |
| Work speed, km/h | 500    | 550-610  | 230     | 255   | 800   | 770   | 750   | 333               | 500    |
| Practical range, km | 170    | 3100     | 500     | 2000  | 5000  | 4500  | 3650  | 2443              | 3800   |
| Practical altitude, m | 940    | 8100     | 6000    | 6500  | 12000 | 12000 | 13000 | 4500              | 11000  |
| Team, people | 3      | 2        | 2-3     | 5     | 7     | 6     | 7     | 2                 | 4      |
| Payload, per, t. cargo | 72 person or 12000 cargo | 24 per., 12 stretcher, 4 t cargo | 16 t water, 4.4 t water or 4 fireman and 5000 cargo or 150 person | 8000 | 8000 | 8000 | 8000 | 790 | 1800 |
| Fuel consumption, kg/h | 1000   | 2300     | 610     | 2540  | 109.5 | 109.5 | 109.5 | 5.8               | 13     |

Agent D, the regional dispatch service of the Federal Forestry Agency, receives information from Agents C, B, L and transfers it to the interagency operations headquarters, which is part of the CSF. The Е1 agents are foot forest firefighters. Having received a command from agents of the K1, K3, K5, they arrive in the zone of natural fire and carry out measures to extinguish it. Their productivity depends on the level of qualification and physical training, as well as on the equipment and equipment available. Agents E are rescue workers run by K2 agents, K4 who directly affect the fire.
Agents M are intended for loosening and moistening the top layer of combustible materials. Depending on the instructions and available technical means, they build mineralized strips of different depth and width. Agents M1 - forest-burning tractors ТЛП-4М JЛХТ-100А-12, ЁЛТ-4ЛЛ. M2 agents - Б-10М bulldozers, M3 agents - trailers - equipment designed for temporary parking sites of responding units, M4 agents - excavators.

Agent N - fire tankers (vehicles). It is an auxiliary technique used to transport and spray a fire extinguishing substance (water or special solutions).

Agent P1 is used to deliver equipment and fire tanks of P2 agents. Agents M, N, P act only on agents of type E.

Agent L1 - specialists of the space monitoring system ISDM Rosleskhoz, which is under the control of FALH, they transmit information to Agent D. Agents of L2 - specialists of the CMS of the Ministry of Emergency Situations of the Russian Federation, EDDS of the municipality monitoring the occurrence of thermal points in the space monitoring system Cascade.

Agents G are paratroopers-firefighters who arrive in a natural fire zone via descent with Agent F. Directly influence a natural fire-agent A.

Agents J - paratroopers-firefighters, they are delivered to the zone of natural fire by means of agent I, act on agents A by manual means of fire elimination.

Agents C are informants who have recorded the fact of ignition by visual observation and transmit information to Agent D.

Agent O - Coordinating body making decisions on the use of forces and means aimed at extinguishing natural fires (it determines the volumes and sources of financing, tactics of fire control).

5. Functioning and interaction of agents in the system "Taiga - Analyst"

Within the scheme discussed (figure 3), Type A agents describing the fire edge may move, modify, remain unchanged, increase, decrease to zero (this corresponds to fire elimination). In a system behind them observation (monitoring) is carried out.

Several methods can be used to determine the initial number and location of agents of type A (fire detection).

1. Space monitoring, which consists of discovering thermal points on the surface of the earth from satellites. In the Russian Federation it is implemented in two ways:
   A) Rosleskhoz ISDM System (Agent L1), from which information is transmitted to the Central Airbase or to the Regional Dispatching Service of the Federal Forestry Agency (hereinafter referred to as RDS) (Agent D);
   B) System Cascade of the Ministry of Emergency Situations (Agent L2), information from this system is registered by the CMS of the Ministry of Emergency Situations of Russia and the EDDS of the municipality or subject of the Russian Federation. The information received from the satellite, which revealed the first fires, is sent to the RDS and the head of the administrative unit of the appropriate level.

2. Ground monitoring is carried out by walking or by travelling by road through forest territory. Observation towers are also used.

The composition and scope of ground monitoring teams depends on the land category. Mark out the following categories of lands: forest land, specially protected areas, including defense and safety.

On forestry lands, patrols are carried out by forestry officers (Agent C4), sometimes with the assistance of a police officer or prosecutor 's office, respectively information on the presence or absence of fires is received by the RDS, forestry or fire-chemical station (hereinafter referred to as PCS) of forestry depending on who is patrolling.

On agricultural lands, reserve lands and settlements, patrols are carried out by the responsible municipality through patrol-control and patrol-maneuvering teams (Agent C1).

Separately it is worth considering the video surveillance system "Yasen" (agent C2), transmitting information to the RDS. Video cameras are located either on cellular towers under the agreement of administrations with operators, or on fire and observation towers (PNV35). Height of such tower 35
meters, angle of view in horizontal plane 360 degrees, Angle of view in vertical plane 40 degrees, range of detection in clear weather is 30 km. Two cameras set up opposite can accurately give the fire coordinate. This system does not work in all constituent entities of the Russian Federation (for example, in the Tomsk region 5 districts are covered with 26 cameras, in the Krasnoyarsk region such video surveillance system does not work in practice).

In the areas in walking distance, as well as logging, the sources of information are also witnesses: the population and tenants of land plots, the field of observation of which is limited to leases and wood removal routes (agent C3) The procedure for informing about the facts of fire is defined by the land plot lease agreement.

3. Aviation monitoring is carried out by means of aviation patrol along pre-developed routes, which is carried out by pilot observers of FALH aviation units (Agent B1), the aircraft may carry paratroopers (today, due to lack of funds, air transportation is carried out by small aircraft, without extinguishing personnel on board). Information from agent B1 is transmitted to RDS.

Information on the fire detected from the air may also be transmitted by civil aviation aircraft (Agent B2) carrying out regular cargo or passenger transport in accordance with agreements of the administration of the subject of the Russian Federation and the air carrier. Information is transmitted through the Air Navigation Service dispatcher (B3 agent) to the RDS.

Regardless of the detection method, the information is sent to the RDS dispatcher and reported to the interministerial operations headquarters, which is part of the KPS (Agent O). If it is necessary and expedient to respond to a natural fire, Agent P shall make a decision and give instructions for the deployment of forces and means to the fire station (Agent K5) nearest to the fire site, which is under the control of forest firefighters (Agents E), as well as to the aviation and ground security base of the subject on the territory of which the fire occurred. On the territory of Krasnoyarsk Territory it is KGAU "Forest Fire Center," which coordinates the operation of aircraft (agents I) and helicopters (agents F), which reduce the temperature of burning forest by discharging water with a helicopter drain device and an aviation fire tank, or deliver to the fire site paratroopers - firefighters (agents J) and paratroopers-firefighters (agents G), respectively. If the efforts of Agents E are insufficient, Agent O shall submit an application to the Federal Forestry Reserve (Agent K3) for the release and delivery of Agents E.

If a fire occurs on the territory of the base or logging site, the tenant (K4 agent) must provide available personnel (up to 5 persons per tenant) Authorized to carry out the extinguishing of natural fires (agents E) and specialized equipment specified in the consolidated plan for extinguishing forest fires of the subject of the Russian Federation (Forest fire tractors (M1 agents), bulldozers (M2 agents), trailers (M3 agents), caterpillar tractors (Agents M4), wheeled tractors (agents M5), excavators (agents M6), cross-country vehicles (Agents M7), fire tankers (agents N), trawls (agents P1), fire tanks (agents P2).

In case of insufficient forces and facilities of FALH and tenants and there is a threat of fire spread or smoke of the settlement, the "Emergency mode" is introduced and the resource of functional subsystems of RSF is activated (K2 agents), which have agents E, I, F, L functional subsystems of the RSF involved in natural fire fighting, also include the Ministry of Civil Defence Disaster Management, Ministry of Defence, Ministry of the Interior.

Type E agents, depending on the forest fire situation, terrain and weather conditions, use various tools: forest ploughs, motor machines, blowers, chainsaw, incendiary vehicles, forest fire extinguishers, shovels, axes, UQV-band radios, KV-band radios and unmanned aerial vehicles (complexes). The selection of the tool has a significant impact on the quenching speed and the result achieved.

The result depends to a large extent on the decision taken at KPS on the choice of the method of extinguishing (units and equipment), the arrangement and volume of forces and means, the necessity and duration of their stay in the fire area.
The result of the implementation of the CPDS should be well-thought-out solutions based on the information foundation, adequate actions, qualified execution and, as a result, timely response with minimal human and material losses.

6. Conclusion
The system "Taiga - Analyst" discussed in this work is intended for operational modeling of parameters of natural fires, assistance of the LPR in the development of fire control solutions. The system allows to assess possible risks for protection objects, helps to train personnel in the basics of tactics of fight against natural fires, to carry out calculation of forces and means necessary for elimination and localization of natural fires.

The system helps to distribute responding units over the protected area, assess the time of fire spread to the protection facility, calculate fire risks, plan patrol routes. At present, the Taiga-Analyst system has found application in the educational process at FSB and in the training and development of specialists in the field of technosphere security. The system has been approved by specialists of the Crisis Management Centers of the Ministry of Emergency Situations of Russia in a number of subjects of the Russian Federation. Work continues to expand the functions and information base of the system and to create a knowledge base for decision-making in the fight against natural fires.

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