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Transformation of Approaches to Determining the Complexity of Fire Response Actions

K.S. Vlasov
EMERCOM of Russia, Balashikha, Russian Federation

ABSTRACT

In most countries of the world, financial metrics are used predominantly to assess the complexity of firefighting and rescue operations. Nowadays, experts are trying to develop a new evaluation system. **The objective** of this research is to explore one of such approaches. **The findings** may prove valuable to managers at all levels, experts in business development and public administration, as well as scientific researchers.

Keywords: fire; fire safety; management; tactics; resources; fire departments

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INTRODUCTION

Theoretical considerations lead to the conclusion that the complexity of a fire is determined by the material losses incurred as a result of the ignition and its subsequent suppression. This approach was developed consistently over the course of nearly a century and was applied initially in the USSR and, after 1992, in the Russian Federation. In the 1990s, following the shift in economic policy from a centrally planned to a market-based model, repeated attempts were made in Russia to transfer certain state functions in the field of fire safety to public and private organisations. For example, fire supervision systems were established within insurance structures and similar institutional arrangements were introduced. At present, however, there remains an objective necessity for state regulation in this area.

By the late 2010s, a rather paradoxical situation had emerged in Russia: for many property owners, it became more convenient not to report the true extent of material losses caused by fires and, in some cases, even to indicate zero damage. This has resulted in the ineffectiveness of the existing system for assessing the tactical complexity of fires and, consequently, in the inability to ensure full-scale management of fire suppression activities.

The maintenance of fire protection services imposes a considerable burden on the state budget. In Russia, the fire safety system operates under continuously increasing requirements for effectiveness and under tightening conditions related to resource provision. To justify the necessary level of such resources, two methods are typically employed. The first involves comparing the fire situation under a hypothetical scenario of a complete absence of fire protection in the country with the actual state of affairs in this sphere[1]. The second relies on assessing the dynamics of key indicators — such as the number of fires, the number of casualties, the magnitude of damage, and others — relative to a baseline level.

The first method provides the most objective results; however, it is rather difficult to apply in practice. The second is considerably simpler, yet it may lead to what can be termed a “stability trap,” whereby prolonged successful performance contributes to the formation of a steady trend of improving reported fire-related indicators and, consequently, creates formal grounds for reducing resource allocation. If the number of fires declines, it is then assumed that expenditures on fire safety should likewise be reduced.

The fire safety system comprises two major directions: the implementation of preventive measures and the suppression of fires by operational response units (the latter hereafter denoted as S_2[2]). The present study examines approaches to evaluating S_2 in order to identify prospective development trends and to substantiate the scale of the required resource provision.

DEVELOPMENT OF A SYSTEM FOR ASSESSING FIRE SCALE AND COMPLEXITY DURING SUPPRESSION OPERATIONS

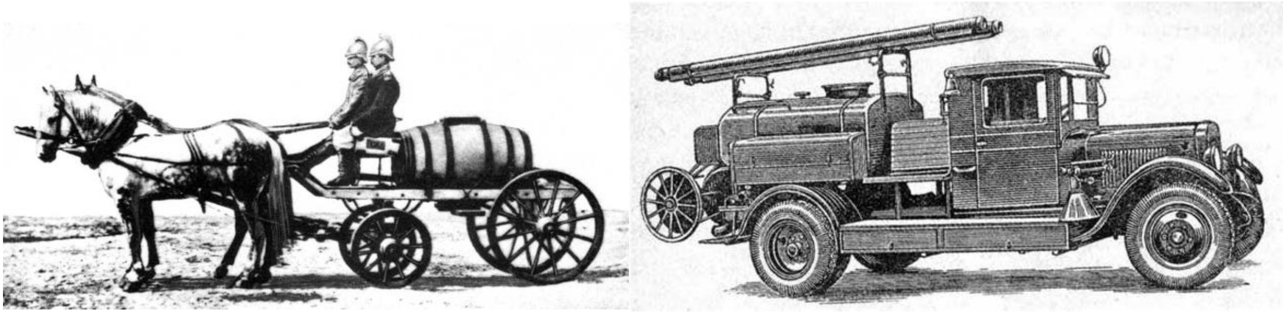
The development of combustion can occur extremely rapidly, as reflected in the proverb “all Moscow was burnt down by a farthing dip[3].” While it is easy to extinguish the flame of a “farthing dip”, as the size of the burning area increases, the amount of resources required to combat a fire grows exponentially. For example, in the eighteenth century, the capacity of fire units was generally sufficient only to eliminate an ignition within a single household. As the fire continued to spread, it typically expanded across the city, and its suppression required the collective efforts of the entire community.

The earliest evidence of organised firefighting teams dates back to the emergence of large cities in the fourth century BCE in Ancient China

[1] Brushlinsky N.N. System Analysis of the Activities of the State Fire Service. Textbook. Moscow: MIPB of the Ministry of Internal Affairs of Russia; 1998. 255 p.

[2] A similar approach is applied in the United States, the European Union, and a number of other countries: fire protection is commonly divided into Passive Fire Protection (PFP) and Active Fire Protection (AFP) and is regulated accordingly by the standards NFPA 3 and NFPA 10.

[3] According to legend, in 1737 the Trinity Fire in Moscow began from a candle (a farthing dip) placed before an icon in the house of the merchant A. Miloslavsky on Znamenka Street



a *b*

Fig. 1. **Fire Transport: a) Horse-drawn Fire Truck, XIX Century; b) Fire Tanker Truck PMZ-2 Model 1935**

Source: Bezborod'ko M., Aleshkov M. [1].

and the Roman Empire[4]. For a long period, nearly all S_2 operations were carried out using manual labour, while fire personnel and equipment were transported by horse-drawn convoys (*Fig. 1a*). The invention of the steam engine in the eighteenth century had a positive impact on S_2 activities; however, overall, the situation remained largely unchanged.

Since the beginning of the twentieth century, horse-drawn convoys in the fire services of Russia and other countries were gradually replaced by motor vehicles. In 1935, the Miussky Plant began the serial production of PMZ-2 fire tanker trucks (*Fig. 1b*), which can be regarded as the starting point of a qualitative re-equipment of the domestic fire service [1]. This modernization enabled firefighting units to operate more independently, without the need to involve military formations, local populations, or other auxiliary forces. However, the downside was a substantial increase in budgetary expenditures required to maintain the fire protection system. From approximately this period onward, both in Russia and abroad, an active search began for opportunities to reduce the costs of the fire safety system and to enhance the economic efficiency of its operations, for which it was decided to rely on financial indicators.

In 1950, the term "large fire[5]" was officially introduced in the USSR. The principal criterion for its definition was the magnitude of damage, which made it possible to identify promising directions for the development of firefighting services based on experience gained from the most tactically complex incidents. Up until the 2010s, this method was actively refined, and a relationship was established between the scale and tactical complexity of fires and the amount of damage they caused. A similar approach is used in the United States, European countries, and other states with well-developed insurance systems [2].

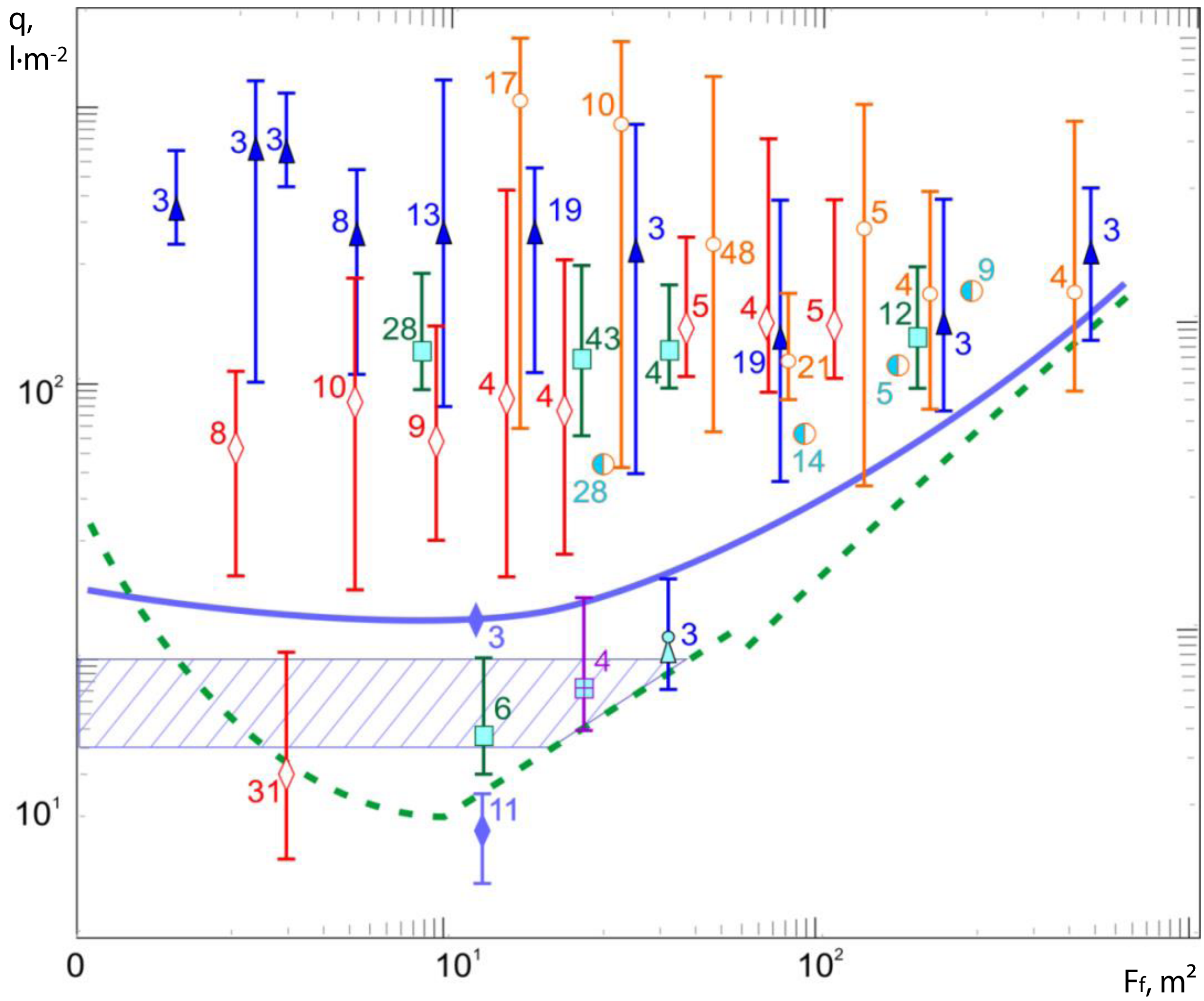
However, in 2017, the officially reported damage from a fire at the "Sindika" shopping centre in Moscow — an incident that required nearly two days of suppression efforts by all fire brigades of Moscow and the Moscow region — was declared by the property owner to be zero rubles. This was far from the first, nor the last, such case. At present, property owners are legally entitled to assess their own losses. While this may offer certain advantages for them, for the fire service it undermines the foundations of a system of fire-scale assessment that had been built over decades. In 2020, this methodology was officially abolished[6].

[4] Abramov V.A., Glukhovenko Yu.M., Smetanin V.F. History of Fire Protection. A Short Course: Textbook. Part 1. Abramov V.A., ed. Moscow: Academy of the State Fire Service of EMERCOM of Russia; 2005. 285 p.

[5] Instruction on the Investigation of Fires. Moscow: Fire Protection Directorate of the Ministry of Internal Affairs of the USSR; 1950. 13 p.

[6] Letter of the Ministry of the Russian Federation for Civil Defence, Emergencies and Disaster Relief (EMERCOM of Russia) dated 23 December 2020 No. M–ID-28. URL: https://normativ.kontur.ru/document?moduleId=8&documentId=380058

Currently, specialists in the fire safety system are seeking alternative indicators and methods for determining fire complexity. The following section considers several approaches to evaluating S_2 activities.



— data from Suchkov A.A., Kolbasin P.A.

— data from Solzberg, Vodraka Maatman

— data from Yavorsky G.A.

Real fires:

— Lobes data

— data from Kiev

— data from Vietnam for 1975–1980 and 1981–1983

— data on Poland

The given figures indicate the number of fires.

Fig. 2. **The Actual Unit Water Consumption for Extinguishing Fires in Residential Buildings at F_f< 50 m², l·m⁻²**

Source: Rodionov E.G. [6].

Notes: where Fp denotes the fire area (m²), and lg(q) indicates that the parameter q is expressed on a logarithmic scale. The dashed line in Figure 2 represents a piecewise linear approximation of this relationship [#].

INDICATOR FOR ASSESSING THE VOLUME OF WORK PERFORMED DURING FIRE SUPPRESSION

At present, as in the past, virtually all fires are extinguished using water [3]. When planning the construction of residential areas and industrial facilities, the capability to ensure the required water flow rate for firefighting purposes (Q_{tr}) is always taken into account.

The earliest attempts to develop quantitative methods for determining Q date back to the 1970s [4]. However, due to the difficulty of providing a rigorous analytical description of the suppression process, this problem was addressed through the synthesis of extensive data from real and experimental fires (*Figure 2*). I.M. Abduragimov and a number of other researchers derived a relationship for the minimum values of specific water consumption (q, L·m^{-2}) required to extinguish solid combustible materials in residential buildings with an area not exceeding 50 m² (1):

$$\lg(q) = 1{,}1 \cdot \lg(F_S) - 0{,}302, \qquad (1)$$

where F_s — denotes the fire area (m²); lg(q) indicates that the parameter q is expressed on a logarithmic scale.

The dashed line in *Figure 2* represents a piecewise linear approximation of this relationship [5] $q = f(F_S)$.

The solid line corresponds to $q = 36F_S^{-0{,}157} + 0{,}5F_S$.

By the mid-1980s, in the USSR and in most countries worldwide, methods and mathematical relationships based on population size were used to determine Q values for urban areas [6]. For comparison, the numerical values of Q were converted into the International System of Units (SI7)[1] and are presented as analytical relationships in the diagram (*Figure 3*).

Let us examine it in greater detail.

- Line 1 reflects the calculations of the American civil engineer and hydraulics specialist J.R. Freeman (1869–1930) (Model 1):

$$Q = 3{,}79N + 189{,}42,$$

[7] The United States currently uses the British Imperial system of measurement for physical quantities.

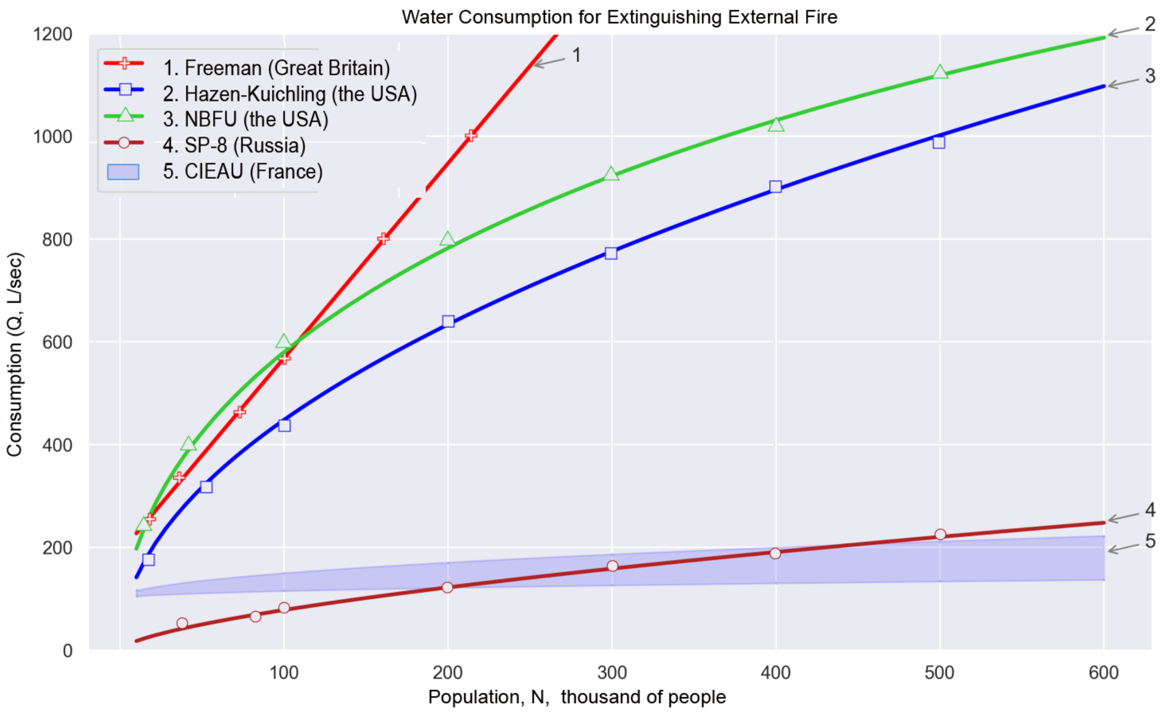


Fig. 3. **Water Consumption (*Q*, L/sec) for Extinguishing External Fire Depending on the City Population**

Source: Compiled by the author.

where N — denotes the city population (persons);

- Curve 2 corresponds to the model proposed by the British hydraulic engineer E. Kuichling (1848–1914) (Model 2):

$$Q = 44,8\sqrt{N};$$

- Curve 3 represents the model of the National Board of Fire Underwriters (NBFU) of the United States (Model 3):

$$Q = 64,35\sqrt{N} - 0,64N;$$

- Curve 4 is constructed in accordance with SP-8 (Russia) (Model 4) [8]:

$$Q = 4,02N^{0,64};$$

- Curve 5 follows the French methodology (Model 5):

$$Q = 100 + c\sqrt{N},$$

where c is an importance coefficient of the object (c = 1,5 … 5).

The substantially higher values of Q in Models 1, 2, and 3 compared with the others can be explained by fundamentally different tactical approaches to S_2 across countries. In the United States, the United Kingdom, and a number of other states, suppression is predominantly carried out using high-capacity water nozzles operated from outside the building. By contrast, the Russian approach requires nozzle operators to select positions in close proximity to the fire seat [7].

Let us assume that there exists a statistical relationship between the indicator of the volume and complexity of work performed during S_2 and the amount of water consumed in the process (ΣQ). In this case, for the purposes of S_2, the value of Q may be adopted as a baseline evaluative indicator on the basis of which the operations of fire and rescue units within the firefighting garrison may be planned. Consequently, as the complexity and volume of work performed at a fire increase, the value of Q should grow proportionally.

On the other hand, a poorly trained unit will likely expend more water when extinguishing a similar fire than a more experienced one. Formally, this may give the impression that the former unit has performed a more complex task. A similar situation is discussed by Karl Marx: "If the value of a commodity is determined by the quantity of labour expended in its production, it might appear that the value of a commodity increases the lazier or less skilled the worker is, since more time is required to produce it" [8, p. 36]. Marx further demonstrates that the appropriate solution lies in the use of average indicators: "Each individual commodity counts here only as an average specimen of its kind" [8].

Approaches to defining the indicator "Volume of operational work performed during fire suppression" have been developed over the years by specialists in fire-technical scientific and educational institutions. Among them, V.M. Gavriley examined labour costs during fire response operations[9] [9]; V.M. Panarin applied differential calculus to model firefighting unit activity [10]; A.V. Terebnev proposed micro-element planning of fire and rescue unit actions [11]; N.N. Brushlinsky analysed workload indicators of operational firefighting units [12], among others. Building on the contributions of these researchers, the author of the present article proposes an approach based on the quantitative assessment of labour input and produced output, where the output is represented by the indicator ΣQ. It is assumed that the workload level of fire and rescue units correlates with the value of Q.

The selection of ΣQ is determined by the following considerations:

- approximately 99% of fires in the Russian Federation are extinguished using water or aqueous solutions [3];

[8] SP 8.13130.2020 — Code of Practice "Fire Protection Systems. External Fire Water Supply. Fire Safety Requirements." URL: https://acs-nnov.ru/assets/files/sp_8.13130.2020_sistemy_protivopozharnoj_zashhity._naruzhnoe_protivopozharnoe_vodosnabzhenie._trebovaniya..._tekst.pdf

[9] Conduct Research and Develop Recommendations for Determining the Required Staffing Levels of Fire Protection and Improving Fire Prevention Activities at Nuclear Power Plants. Research Report / All-Union Research Institute for Fire Protection of the Ministry of Internal Affairs of the USSR (VNIIPO MVD USSR). Moscow; 1986. 188 p.

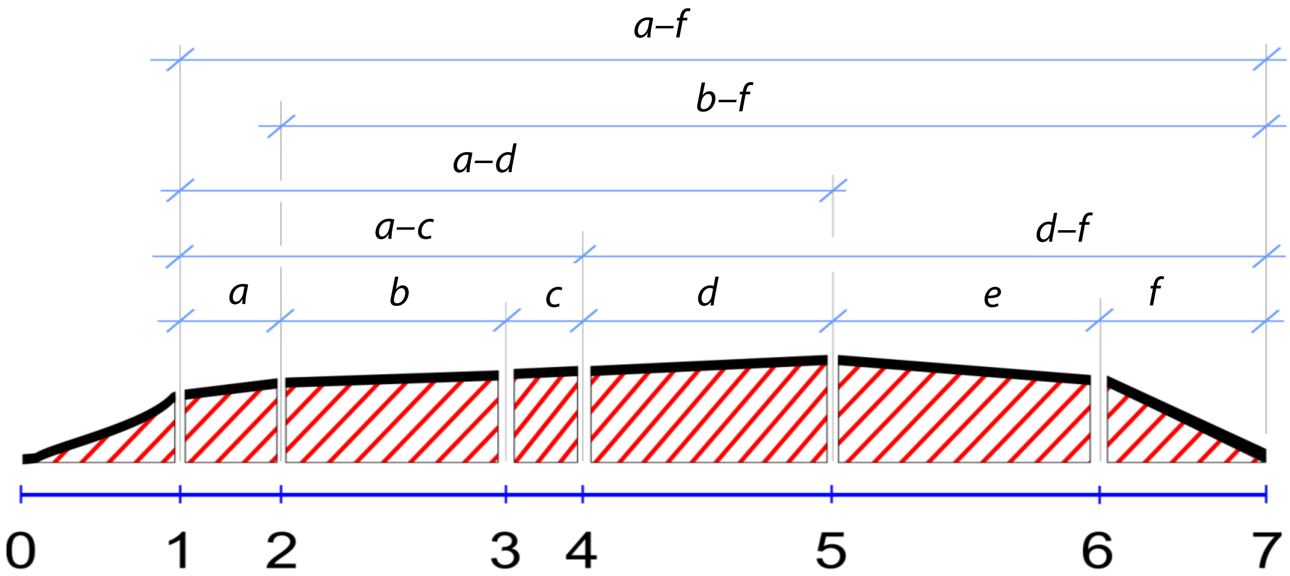


Fig. 4. **Fire Development Intervals**

Source: Compiled by the author.

Notes: 1) 0 — occurrence; 1 — detection; 2 — message; 3 — arrival; 4 — supply of the 1st trunk for extinguishing; 5 — localization; 6 — liquidation; 7 —elimination of consequences.
2) Intervals: a —message; b — follow; c — supply of the 1st barrel; d — localization; e —elimination of open combustion; f — elimination of consequences; a–c —free burning; d–f — fire extinguishing; a–d — concentration; b–f — time of employment on fire; a–f — call service.

• the "FBD-Fires[10]" database contains factors that allow ΣQ to be determined with a high degree of reliability, including parameters describing time intervals — $\tau_{a\text{-}d}$, $\tau_{d\text{-}f}$ (*Figure 4*), the number and types of water delivery devices used, the number of fire engines, and the duration of smoke-diving service deployment;

• reference data are available regarding the performance capacity of water delivery devices (q_{stv}, L/s) employed by fire and rescue units[11] [13].

Let us consider the empirical relationship (2):

$$Q = f\left(3{,}7N_{\text{stvB}} + 7{,}4N_{\text{stvA}} + 21N_{\text{LF}} + 5{,}64N_{\text{GPS}}\right), \quad (2)$$

where N denotes the number of nozzles of the respective types (RS-50, RS-70, monitor nozzles) and foam generators (respectively), expressed in units; f presents various functions[12] applied depending on the specific task.

This approach makes it possible, *first*, to determine ΣQ for routine (day-to-day) S_2 operations in response to ordinary fires occurring within the territory of the fire and rescue garrison; and *second*, to assess the required reserve of forces and resources available for the rapid operational scaling-up of Q when suppressing large-scale fires.

SIMULTANEOUS FIRES

A distinctive feature of fires is the possibility of their simultaneous occurrence in different locations within the territory of a single city. In such cases, one of the most challenging tasks for fire and rescue units becomes the organisation of S_2 activities and the rational allocation of the fire and rescue group resources, while the degree of operational complexity increases as the scale of the incident grows.

Simultaneous fires are defined as those whose time intervals (τ_{a-f}) overlap. Prior to the early 1970s,

[10] Federal database for storing data on fires registered in the territory of the Russian Federation. Maintained by the Ministry of the Russian Federation for Civil Defence, Emergencies and Disaster Relief (EMERCOM of Russia).

[11] Melnik A. A., Martinovich N. V., Kalyuzhina Zh.S., Malyutin O.S. Handbook for a Fire Station Watch Commander. Krasnoyarsk: Siberian Fire and Rescue Academy of the State Fire Service of EMERCOM of Russia; 2019. 176 p.

[12] Vlasov, K.S. Applied Methods for Studying the Operational Activities of Fire and Rescue Units: Problems and Solutions: A Study Guide. Moscow: VNIIPO, 2023. 406 p.

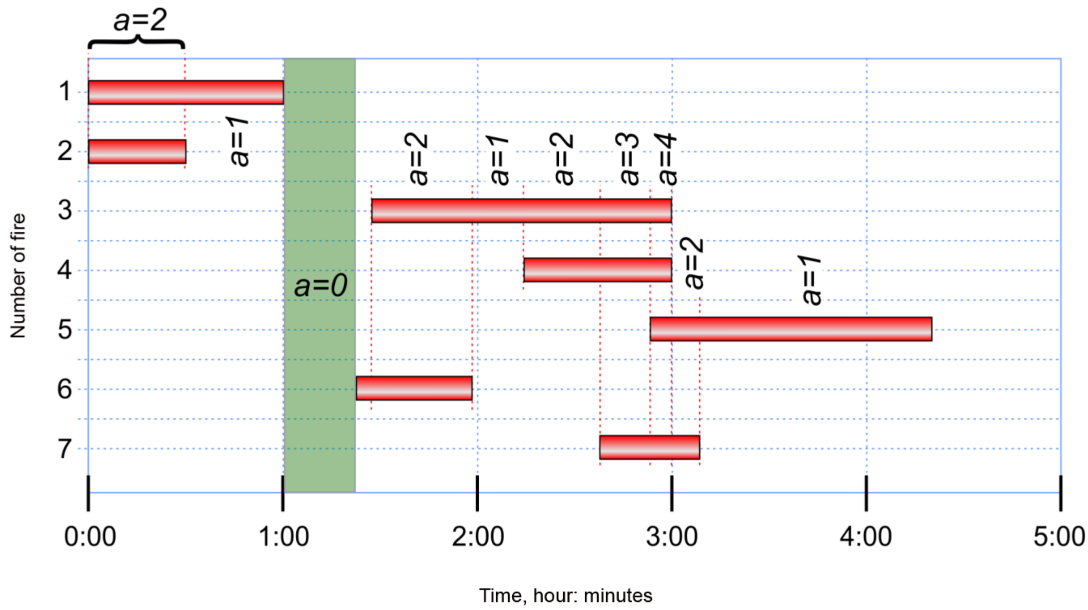


Fig. 5. **Gantt Chart**

Source: Compiled by the author.

Note: according to the approach of N.A. Tarasov-Agalakov, all fires indicated on the diagram are considered simultaneous; simultaneous fires from the point of view of N.N. Brushlinsky are those with the intervals "a>0".

in Russia all fires occurring within the same settlement during three consecutive hours were considered simultaneous, regardless of their scale or duration. This approach was substantiated by the scholar and organiser of advanced professional training for fire protection personnel, N.A. Tarasov-Agalakov [14]. One of his arguments was the necessity of restoring fire and rescue units to operational readiness (refilling water supplies, replacing used equipment, and so forth), a process requiring approximately three hours. Tarasov-Agalakov assumed, for example, that all cases shown in the diagram (*Fig. 5*) should be regarded as simultaneous, even taking into account the interval indicated by the green band, which represents a fire-free period.

ANALYSIS OF EMPLOYMENT TIME

By the 1970s, another modernisation of firefighting equipment and technology had been carried out, which made it possible to significantly reduce the time required to restore the operational readiness of fire and rescue units. Consequently, the specialist in mathematical modelling of complex systems and applied statistics, N.N. Brushlinsky, examined the activities of fire and rescue units through the lens of probability theory and queuing theory, interpreting them as a class of Markov ergodic stochastic processes in continuous time [15]. Within this framework, only those fires that truly overlapped in time were considered simultaneous — for instance, cases No. 1 and 2 within the interval "a = 2" (see *Fig. 5*). Accordingly, the diagram allows the identification of four segments during which two fires were occurring simultaneously in the city, as well as one segment each with three and four concurrent fires.

In the legislation of many countries, the possibility of simultaneous fires is taken into account. In particular, in the United Kingdom, the staffing and resources of fire services are determined based on the assumption of two simultaneous fires in one city. In the United States, a similar calculation is applied to cities with populations exceeding 200,000 [6].

For the practical identification of simultaneous fires, a minimum interval of one minute was adopted. This choice was based on the following considerations: first, the same interval is used in the "FBD-Fires[13]" database; second, empirical tests have

[13] Order of the Ministry of the Russian Federation for Civil Defence, Emergencies and Disaster Relief No. 714 of 21 November 2008 "On Approval of the Procedure for Recording

Fire	Vector of minutes									
	1	2	3	4	5	6	7	...	7889759	7889760
1	1	1	1	1	0	0	0	...	0	0
2	0	0	1	1	1	1	0	...	0	0
...	...	...	...	...	...	...	...	...	...	...
N	0	0	0	1	1	1	1	...	0	0
Σ	1	1	2	3	2	2	1	...	0	0

Fig. 6. **Gantt Chart for Determining the Employment Rate of Fire Departments**

Source: Compiled by the author.

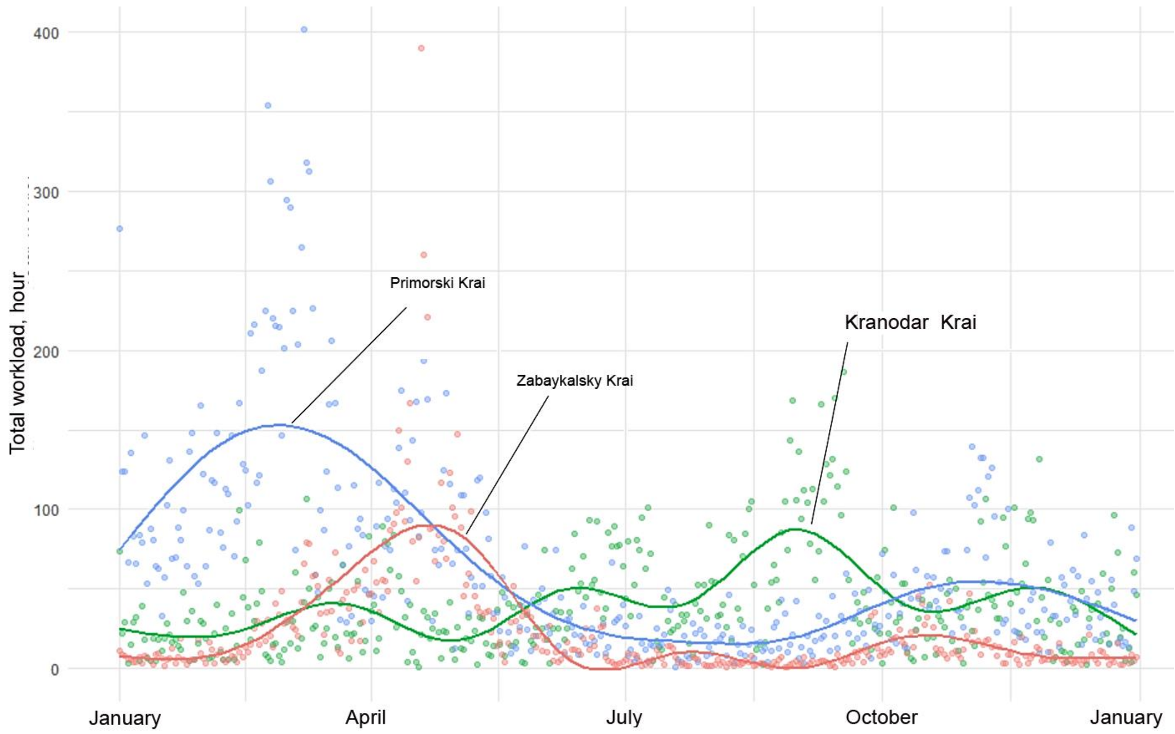


Fig. 7. **Indicators of the Total Daily Employment of Fire and Rescue Units in the Zabaykalsky, Krasnodar and Primorsky Krai (for the year of 2020)**

Source: Compiled by the author.

demonstrated the suitability of this measurement unit for describing the actions of fire and rescue units [16].

Using this method, we construct a row vector

$$x_t = (a_1, .., a_i, \ldots, a_n),$$

where $a_1 = 0$ corresponds to the beginning of the interval on 01.01.2010 at 00:00, and $a_n = 7{,}889{,}760$ corresponds to its end on 31.12.2024 at 23:59:59. The vector x_t constitutes a discrete stochastic time series with a fixed step of one minute.

Next, for each a_i, it is necessary to determine the number of fires occurring during the i — th minute ($a_i = 0$ if no fires are observed in the i — th minute).

The calculations included only cases satisfying the following conditions (C_3):

- fire and rescue units responded to the call and carried out S_2 operations; for example, if a fire was extinguished before their arrival, the case is not considered a fire event for the units, since no suppression actions were required;
- firefighting devices for delivering extinguishing agents were necessarily used during S_2 (figura-

Fires and Their Consequences." URL: https://mchs.gov.ru/uploads/document/2024–01–22/36a3b2a6333c2aaeaa759acb23a040ea.pdf

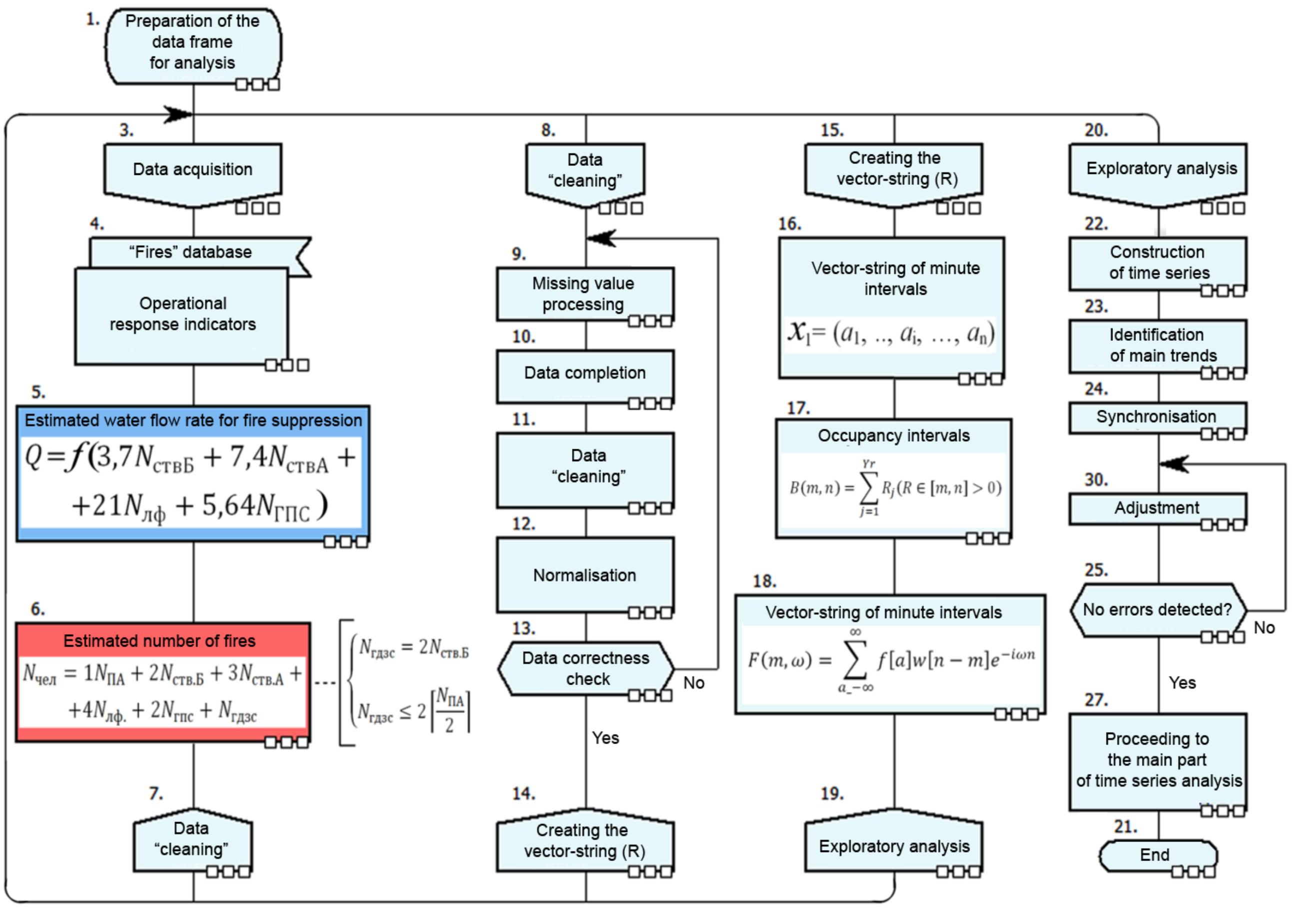


Fig. 8. **The General View of the Data Preparation Algorithm for Time Series Analysis Using Python Tools**

Source: Compiled by the author.

tively speaking, if combustion is eliminated with a single cup of water, it is not classified as a fire);

- the data fields in the fire incident report were completed correctly[14].

ANALYSIS OF OCCUPANCY TIME

By analogy with the calculation of *Q*, it is possible to construct a Gantt chart for x_t and determine aggregate occupancy indicators (Σ) for each minute (*Fig. 6*).

An analysis of the time-occupancy measures of fire and rescue units during fire incidents revealed the presence of certain regularities. This is illustrated by the example of an annual additive workload model for fire and rescue units, both for Russia as a whole and for individual regions in 2020 (*Figure 7*).

[14] Ibid. Annex 1.

Similar distributions of these indicators were observed in other years as well (from 2010 to 2024).

Let us consider this situation using the city of Chita in Zabaykalsky Krai as an example. Between 2010 and 2024, a total of 33 942 fires occurred in the city that satisfied the conditions of C_3. Applying the method proposed by N.N. Brushlinsky (see *Fig. 5*), we determine the number of simultaneous fires in Chita. Practical calculations and data processing were carried out using the Pandas, NumPy, and Scikit-Learn modules of the Python programming language according to the following procedure (*Fig. 8*).

Over the 15-year period under consideration, more than two thousand simultaneous fires occurred in the city; and on two occasions — in 2014 and 2019 —there were 14 fires whose time intervals partially overlapped. The overlaps were calculated using formula (3):

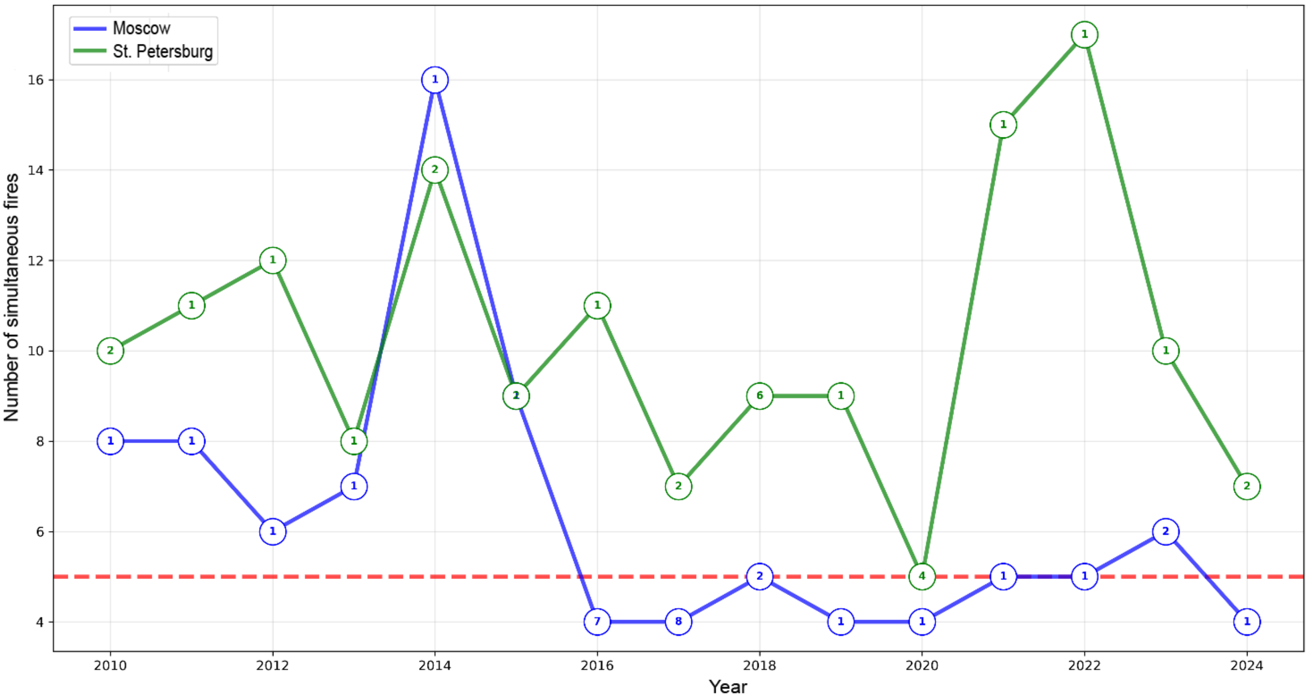


Fig. 9. **Dynamics of the Maximum Amount of Simultaneous Fires in Moscow and St. Petersburg in 2010–2024.**

Source: Compiled by the author.

Note: In the circles on the lines is the maximum number for simultaneous fires per year. The dotted line is the standard value.

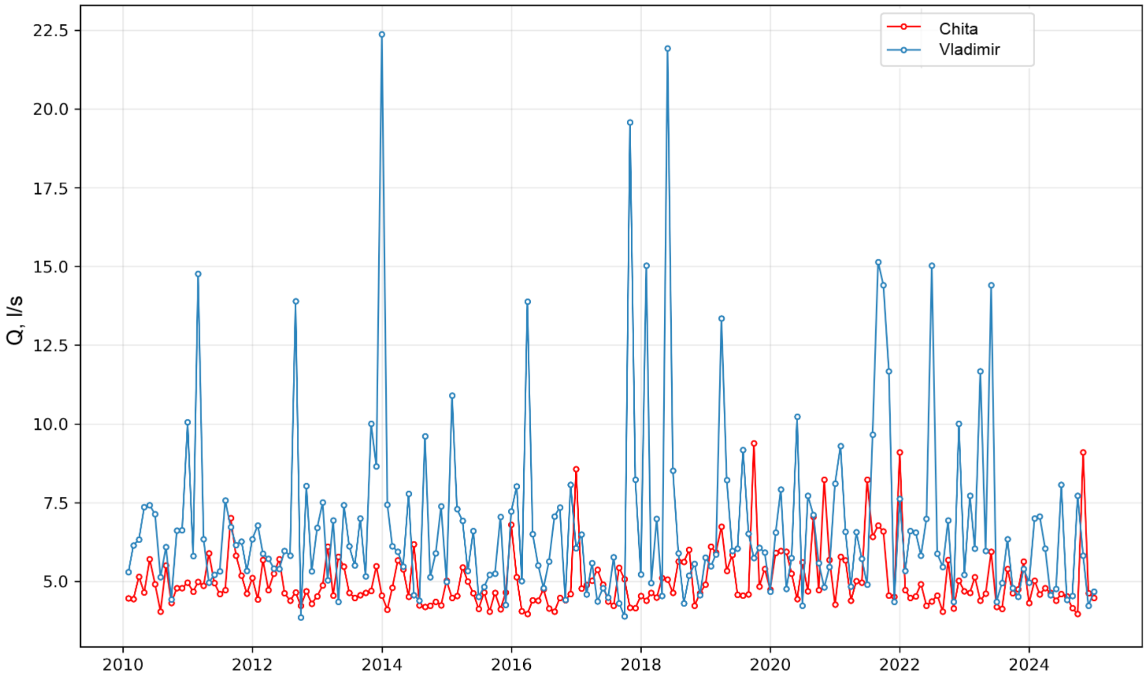


Fig. 10. **Dynamics of Average Water Consumption During Fires in the Cities of Vladimir and Chita by months for the Years of 2010–2024**

Source: Compiled by the author.

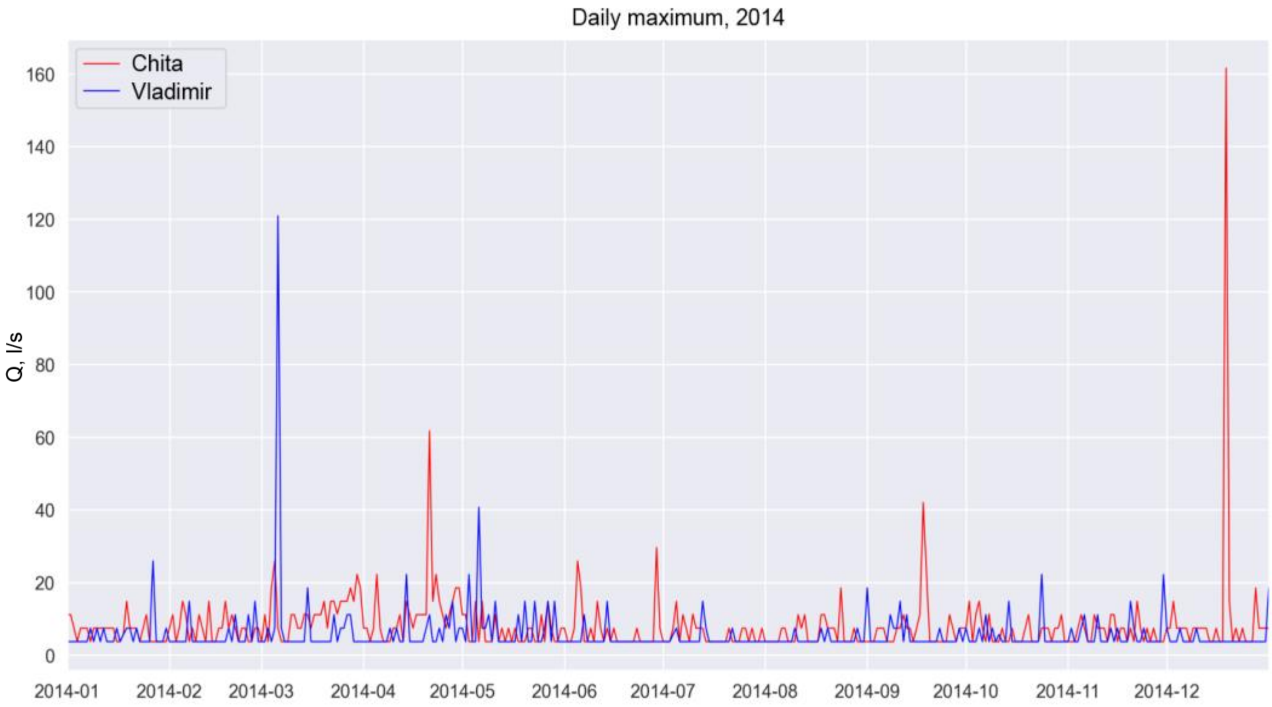


Fig. 11. **Dynamics of Maximum Indicators of Daily Water Consumption During Fires in the Cities of Vladimir and Chita in 2014**

Source: Compiled by the author.

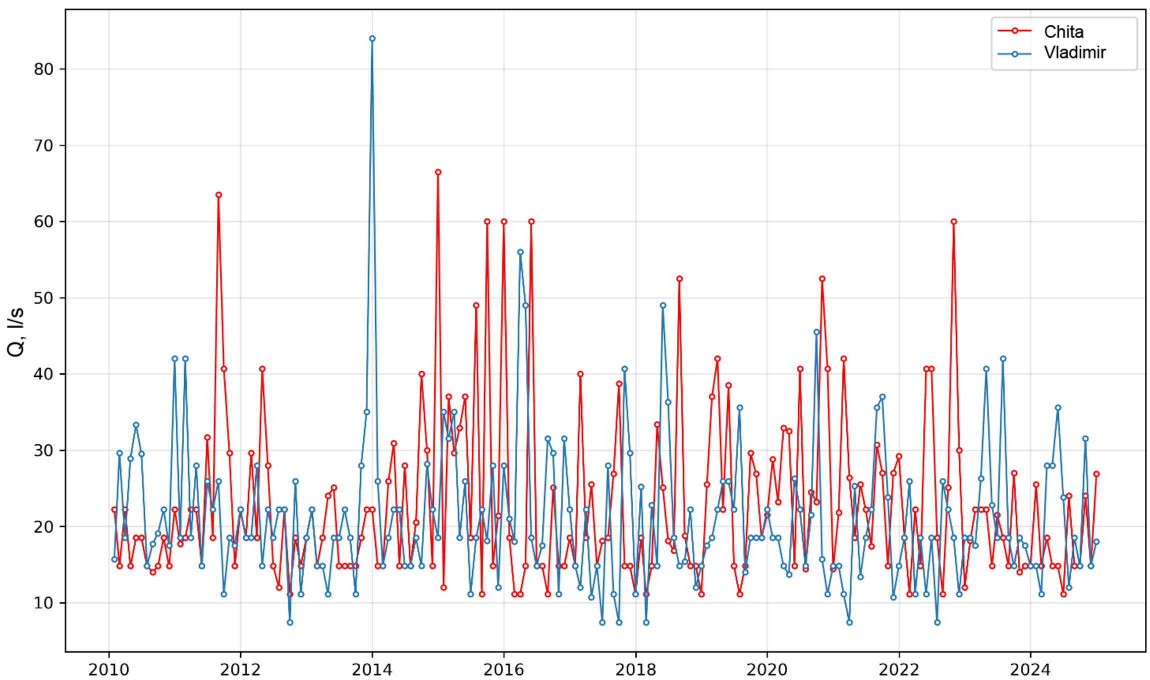


Fig. 12. **Dynamics of Maximum Water Consumption Indicators by Month for Fires in the Cities of Vladimir and Chita in 2010-2024**

Source: Compiled by the author.

$$B(m,n) = \sum_{j=1}^{Yr} R_j \left(R \in [m,n] > 0 \right), \quad (3)$$

where m and n denote the boundaries of the unit row vector; Yr represents the duration of the interval from 2010 to 2024 measured in minutes; and R_j is a random variable indicating the occurrence of a fire event, provided that R belongs to the interval ($[m, n] > 0$).

In Russia, the number of simultaneous fires constitutes one of the factors used to determine the regulatory value of Q_{tr}, which is required to ensure external fire suppression in urban settlements[15]. For example, in cities with populations exceeding one million, it is calculated on the basis of five simultaneous fires. However, in practice, a different situation is observed (*Figure 9*). For instance, in 2014, a case involving 16 simultaneous fires was recorded in Moscow, whereas in 2016 and 2017 (and on several other occasions) the indicator was below the prescribed standard.

A similar pattern is found in other cities as well.

Let us compare the actual dynamics of the Q indicator from 2010 to 2024 for the cities of Vladimir and Chita. During this period, the population of each city averaged approximately 350,000 residents, while the calculated number of simultaneous fires was three[16]. In Vladimir, a total of 7,964 fires satisfying the C_3 conditions occurred over the 14-year period under consideration, which is significantly fewer than in Chita (33,942).

The average value Q_{avr} is typically applied in long-term planning of fire safety system parameters. As the analysis demonstrates, Q_{avr} is strongly influenced by factors associated with the large number of ordinary fires, the share of which reaches up to 99%.

The distributions of the Q_{avr} indicator (*Fig. 10*) for Vladimir and Chita differ markedly, despite the nearly identical population size of the two cities. This observation, for the period from 2010 to 2024, refutes the existing hypothesis of a correlation between population size and the factors characterising the state of the fire safety system [15] (see *Fig. 3*).

In addition to simultaneous fires, real-life conditions may also involve phenomena referred to as large-scale fires. Their suppression requires the deployment of fire and rescue group resources at the maximum level. The diagram (*Fig. 11*) shows sharp spikes in Q for Chita and Vladimir. Coincidentally, both events occurred in 2014: in Vladimir, a major fire broke out on 3 May at the warehouse of the Globus hypermarket, while in Chita, a large fire occurred on 18 December at the "Vysokogorye" sports and recreation complex.

In both cases, the time series contain so-called "gaps," that is, days when no fires were recorded in the city or only minor ignitions occurred that did not satisfy the $У_3$ conditions.

FORECASTING WATER CONSUMPTION FOR FIRE SUPPRESSION

In forecasting-related tasks, evaluation of results is usually based on measures of central tendency (mean, median, etc.). The primary purpose of such methods, originally developed to address commercial objectives, is to increase profitability indicators. In the case of fires, however, this approach is not entirely appropriate, since a fire is a destructive event whose occurrence is highly undesirable. The application of such tools in the field of fire safety would require certain adjustments, because the main objective of fire and rescue units is to reduce damage and other economic losses.

As is well known, historical information gradually loses its influence on predicted outcomes over time. Therefore, in order to construct a reliable forecast for the next two to three years, it is advisable to consider data from approximately the last five to six years. Information obtained from earlier periods is needed to assess the overall dynamics of the process as a whole [17]. With regard to the activities of fire and rescue groups, planning can be understood as a practical activity aimed at de-

[15] Set of Rules SP 8.13130.2020 "Fire Protection Systems. External Firefighting Water Supply. Fire Safety Requirements "URL: https://acs-nnov.ru/assets/files/sp_8.13130.2020_sistemy_protivopozharnoj_zashhity._naruzhnoe_protivopozharnoe_vodosnabzhenie._trebovaniya..._tekst.pdf
[16] Ibid.

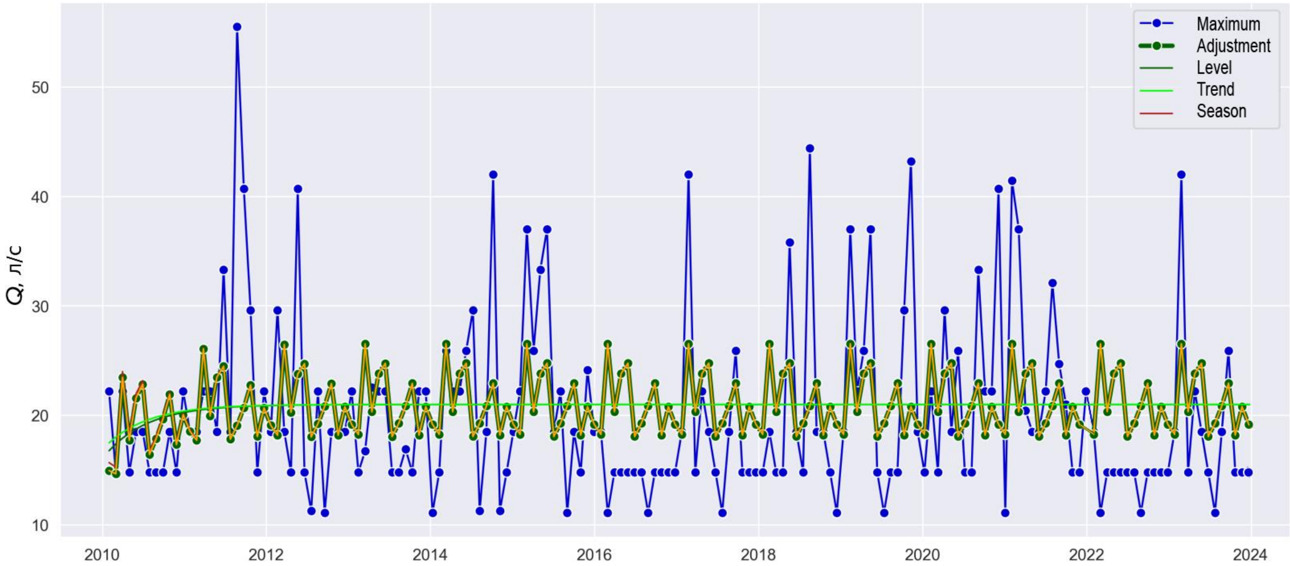


Fig. 13. **Calculated Indicators of Water Consumption for Fire Fighting in Chita**

Source: Compiled by the author.

veloping a strategy for the development of the fire garrison[17] [13].

Above (see the section "Indicator for Evaluating the Completed Volume of Fireground Work"), it was proposed to adopt the indicator Q_{tr} for planning the activities of fire and rescue groups with respect to task S_2, since it objectively reflects the use of the main material resource — water — and, in general, the volume of work performed by fire and rescue units during a fire.

A sufficiently comprehensive set of information on fires in the Russian Federation is contained in the Federal Fire Database "Fires." Although this database does not record the value of Q, it can be approximately determined using formula (2), based on the number of devices employed at a fire to deliver extinguishing agents.

The diagrams of maximum values Q_{max} for Vladimir and Chita (*Fig. 12*) may be regarded as representations of random time series $Q(t)$. In that case, in order to assess their current changes and forecast future transformations, the additive model equation (4) can be applied:

$$Q(t) = s_t + b_t + S_t + \varepsilon, \qquad (4)$$

where s_t denotes the level of the time series, b_t is the overall trend component, S_t represents the seasonal component, and ε is Gaussian noise.

After preliminary data processing according to the algorithm (see *Fig. 8*), an exponential smoothing procedure is applied. As a result of the calculations, the values of Q were determined using Chita as an example (*Fig. 13*).

Aggregate indicators for Chita and several other Russian cities with populations ranging from 300,000 to 400,000 residents are presented in the *Table*.

Positive values of b_t (4) over the 2018–2021 interval indicate the need for a consistent increase in Q in Vladimir, Arkhangelsk, and Kurgan, whereas in the remaining cities there are prerequisites for a reduction of this indicator.

Using calculations based on the methodology applied in the USSR [6], in the 1980s a standard value of Q_{norm} = 70 L/s was established for all cities with populations ranging from 300,000 to 400,000 residents. This value is still reflected in current regulatory documents[18] and, as can be

[17] Baille S., Philippe R., Braudel. F. Le Monde actuel histoire et civilisation.. Livre scolaire: histoire / géographie. Belin: 1963.

[18] Set of Rules SP 8.13130.2020. Fire Protection Systems. External Fire Water Supply. Fire Safety Requirements. URL: https://acs-nnov.ru/assets/files/sp_8.13130.2020_sistemy_protivopozharnoj_zashhity._naruzhnoe_protivopozharnoe_vodosnabzhenie._trebovaniya..._tekst.pdf

Table

Recommended Calculated Water Consumption Rates for Fire Extinguishing (Q, l×s^{-1}) for Some Cities of the Russian Federation with a Population of 300–400 Thousand People

Month	City					
	Chita	Vladimir	Arkhangelsk*	Belgorod	Kaluga	Kurgan
January	18.3	19.4	34.7	8.8	14.1	18.7
February	26.5	12.0	32.8	7.3	13.4	22.2
March	20.3	22.2	32.5	9.2	16.0	23.9
April	23.8	21.2	28.4	11.6	16.7	33.7
May	24.8	22.0	40.0	13.5	13.3	24.0
June	18.1	18.8	41.0	11.0	13.2	25.0
July	19.3	18.5	37.3	8.2	14.7	20.1
August	20.9	17.6	36.9	9.8	12.3	20.8
September	18.2	20.7	24.6	9.7	12.0	17.3
October	20.8	25.1	30.2	10.1	13.3	18.4
November	19.2	15.9	35.1	11.9	11.8	18.8
December	18.3	19.4	34.7	8.8	14.4	18.7
Population in 2024.	333.2	341.6	296.7	321.8	329.7	302.4
Trend, b_t	$-2.57\cdot10^{-6}$	$1.50\cdot10^{-4}$	$4.32\cdot10^{-4}$	$-2.52\cdot10^{-4}$	$-1.3\cdot10^{-3}$	$3.4\cdot10^{-5}$
Q_{max}, l/s	161.6	120.9	142.0	117.7	87.6	147.0

Source: Compiled by the author.

Note: * — The population of Arkhangelsk decreased to less than 300 thousand people after 2022.

seen, substantially exceeds actual observed indicators. For its time, such a standard value of Q_{norm} was justified from a practical perspective. However, under contemporary conditions, discrepancies between real and prescribed values of Q and Q_{norm} can be readily identified for each city using information technologies. In the future, a transition is likely toward a new differentiated system of standardising Q_{tr}, based on the data presented in the *Table*, which may lead to a significant reduction in expenditures on fire water supply in urban settlements.

At the same time, it is important to keep in mind the real threat of large-scale fires, during which the actual value of Q may exceed Q_{norm} by several times. For Vladimir and Chita, once every 10–12 years a fire may occur requiring $Q \approx 160$ L/s in Chita (as in 2014) and $Q \approx 120$ L/s in Vladimir. Therefore, it is necessary to ensure the technical capability for the rapid scaling-up of Q to its maximum values.

Similar calculations were also carried out to determine the actual routine demand of the fire and rescue garrison for firefighting equipment and staffing levels. For clarity, these data can be presented as a range of indicators sorted in ascending order (*Fig. 14*).

The height of the bars in the diagram corresponds to the calculated number of firefighting personnel required to ensure the delivery of the estimated Q value across the 85 regions of the Russian Federation. The highest staffing demand is observed in Altai Krai. In the Khanty-Mansi Autonomous Okrug, there are grounds for

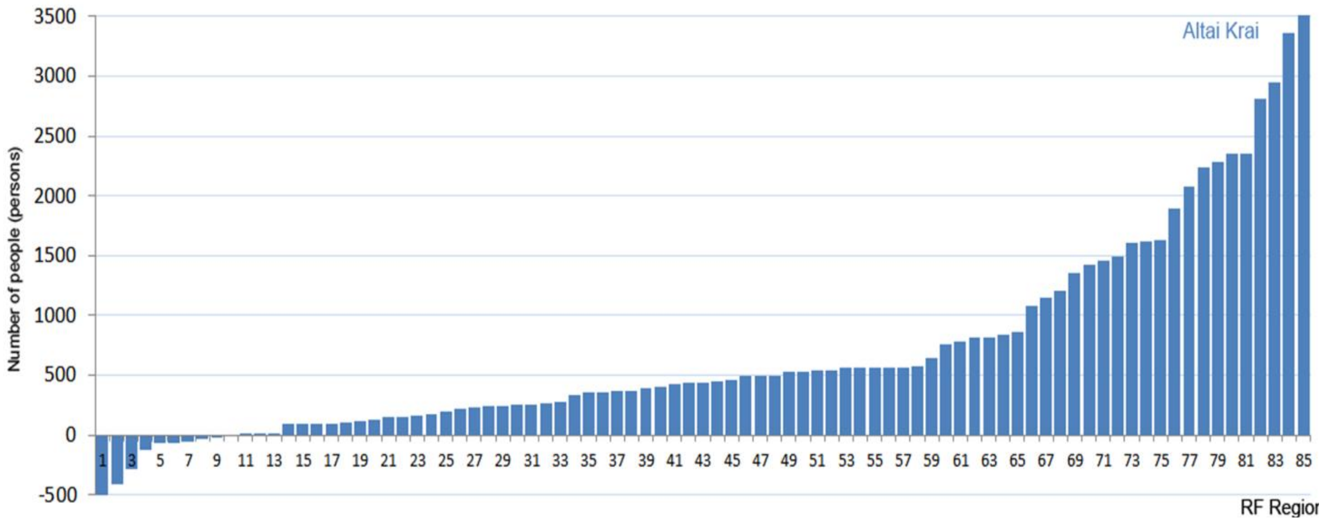


Fig. 14. **Ranges of Changes in the Minimum Number of Fire Departments**

Source: Compiled by the author.

Note: a– The minimum is in the Khanty-Mansiysk Autonomous Okrug, the maximum is in the Altai Territory; b – Federal subjects of the Russian Federation in numerical order:

1. Khanty-Mansi Autonomous Okrug – Yugra
2. Moscow
3. Republic of Tatarstan (Tatarstan)
4. Yaroslavl Oblast
5. Republic of Crimea
6. Lipetsk Oblast
7. Krasnoyarsk Krai
8. Penza Oblast
9. Republic of Ingushetia
10. Ivanovo Oblast
11. Republic of Khakassia
12. Tver Oblast
13. Vladimir Oblast
14. Republic of North Ossetia-Alania
15. Novosibirsk Oblast
16. Kostroma Oblast
17. Altai Republic
18. Khabarovsk Krai
19. Sakhalin Oblast
20. Kaliningrad Oblast
21. Republic of Karelia
22. Nizhny Novgorod Oblast
23. Kamchatka Krai
24. Ulyanovsk Oblast
25. Belgorod Oblast
26. Rostov Oblast
27. Republic of Mordovia
28. Smolensk Oblast
29. Arkhangelsk Region
30. Republic of Buryatia
31. Kursk Region
32. Chuvash Republic - Chuvashia
33. Orenburg Region
34. Vologda Region
35. Republic of Kalmykia
36. Samara Region
37. Kemerovo Region - Kuzbass
38. Primorsky Krai
39. Republic of Tyva
40. Saint Petersburg
41. Jewish Autonomous Region
42. Republic of Adygea (Adygea)
43. Chukotka Autonomous Okrug
44. Irkutsk Region
45. Komi Republic
46. Pskov Region
47. Amur Region
48. Tomsk Region
49. Chechen Republic
50. Kurgan Region
51. Nenets Autonomous Okrug
52. Republic of Sakha (Yakutia)
53. Sverdlovsk Region
54. Bryansk Region
55. Novgorod Region
56. Republic of Dagestan
57. Chelyabinsk Region
58. Voronezh Region
59. Krasnodar Region
60. Oryol Region
61. Karachay-Cherkess Republic
62. Saratov Region
63. Kaluga Region
64. Transbaikal Territory
65. Leningrad Region
66. Omsk Region
67. Stavropol Territory
68. Kirov Region
69. Udmurt Republic
70. Tambov Region
71. Republic of Bashkortostan
72. Murmansk Region
73. Astrakhan Region
74. Sevastopol
75. Mari El Republic
76. Volgograd Region
77. Yamalo-Nenets Autonomous Okrug
78. Magadan Region
79. Perm Region
80. Tyumen Region
81. Kabardino-Balkarian Republic
82. Tula Oblast
83. Moscow Oblast
84. Ryazan Oblast
85. Altai Krai

c – New subjects of the Russian Federation are not considered in the study due to the lack of objective statistical data.

reducing personnel numbers by approximately 500 individuals. However, this applies only to the core operational units performing S_2 tasks. The staffing levels of managerial personnel and units responsible for fire prevention, logistical support, and other functions are determined using a separate methodology.

CONCLUSION

At present, virtually all fires are extinguished using water. Based on the conducted study, the following conclusions can be drawn:

The system for assessing the fire safety framework and, in particular, the activity of operational firefighting units in fire suppression (S_2), which has traditionally been based on the magnitude of associated material losses, has lost its relevance under contemporary conditions. In the proposed model, the baseline indicator is the *water flow rate used for fire suppression* (Q, L/s).

The historically established approach to standardising the required firefighting water demand (Q_{tr}) in cities — based on population size and factors broadly characterising fire hazard in urban development or industrial facilities — is not always justified in present-day circumstances. As demonstrated in the article, the fire situation in Vladimir and Chita, despite their nearly identical population size, differs substantially.

The findings indicate that, given the current level of scientific and technological development, there is a practical possibility to determine the current value of Q_{tr} for each city more accurately and for different time periods.

The calculated values of Q_{tr} are several times lower than those prescribed by existing standards, which, in our view, opens opportunities for modernising the current fire water supply system through technical and organisational redistribution of water provision resources.

The maximum Q_{tr}, most frequently arising during simultaneous and large-scale fires and exceeding the prescribed standard by multiple times, should be treated as a reference level to which Q must be locally and temporarily increased when necessary. During ordinary conditions, it should be maintained at the calculated operational level.

Thus, a new system for organising the activity of operational firefighting units in fire suppression, based on the calculation of water consumption indicators, makes it possible to substantiate the required staffing levels of fire and rescue units and ensure an adequate level of resource provision. The implementation of this system is consistent with broader societal trends aimed at enhancing environmental sustainability and promoting a more responsible use of water resources.

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ABOUT THE AUTHOR

Konstantin S. Vlasov — Head of Department, VNIIPO EMERCOM of Russia, Balashikha, Russian Federation
https://orcid.org/0000-0003-2499-169X
vlasov-k@yandex.ru

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