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Methods of Determining Forces and Equipment in the Designing of Fire and Rescue Services

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Annotation: This article explains the algorithm of determining the forces and equipment necessary for fire and rescue services in the designing of fire and rescue garrison services organized to ensure the fire safety of cities, regions and settlements.

Keywords: fire and rescue service, fire and rescue depot, fire and rescue vehicle, queuing system, algorithm, average arrival time, forces and equipment.

To ensure fire safety of residential areas of the republic the requirements of several existing regulatory documents in the organizational design of fire-rescue services economic difficulties may arise in practical application and lack of organizational design normative legal documents on the arrival of fire-rescue units to the place of call on the basis of a fixed time makes it difficult to ensure fire safety at the required level [1].

In this regard, by applying the rules of the modeling theory of fire-rescue services, it allows to systematize the existing algorithms in the design of units and to develop the algorithm presented in Figure 1 for determining the depots, forces and tools necessary for the republican city and district fire-rescue services. It is desirable to implement this algorithm in the following steps [2]:

1. In the first stage determined depending on the average time $\bar{\tau}_{a.pl}$ of arrival of the fire and rescue service units to the place of call and theaverage speed of movement.

2. In the second stage, which takes into account average arrival time $\bar{\tau}_{a.pl}$ (km/min), average movement speed $V_{pl} = 25 \div 45$ km/h (fire chief data set), non-linearity factor of the street network K_n, where the area of the settlement $S_{pop}\,(\mathrm{km}^2)$ varies from 1 to $\sqrt{2} \approx 1{,}4$ according to the urban network, and the characteristics of each settlement α and is often performed taking into account the dimensionless empirical coefficient, which is in the range from $\alpha = 0{,}3 \text{ to } 0{,}5$ [3].

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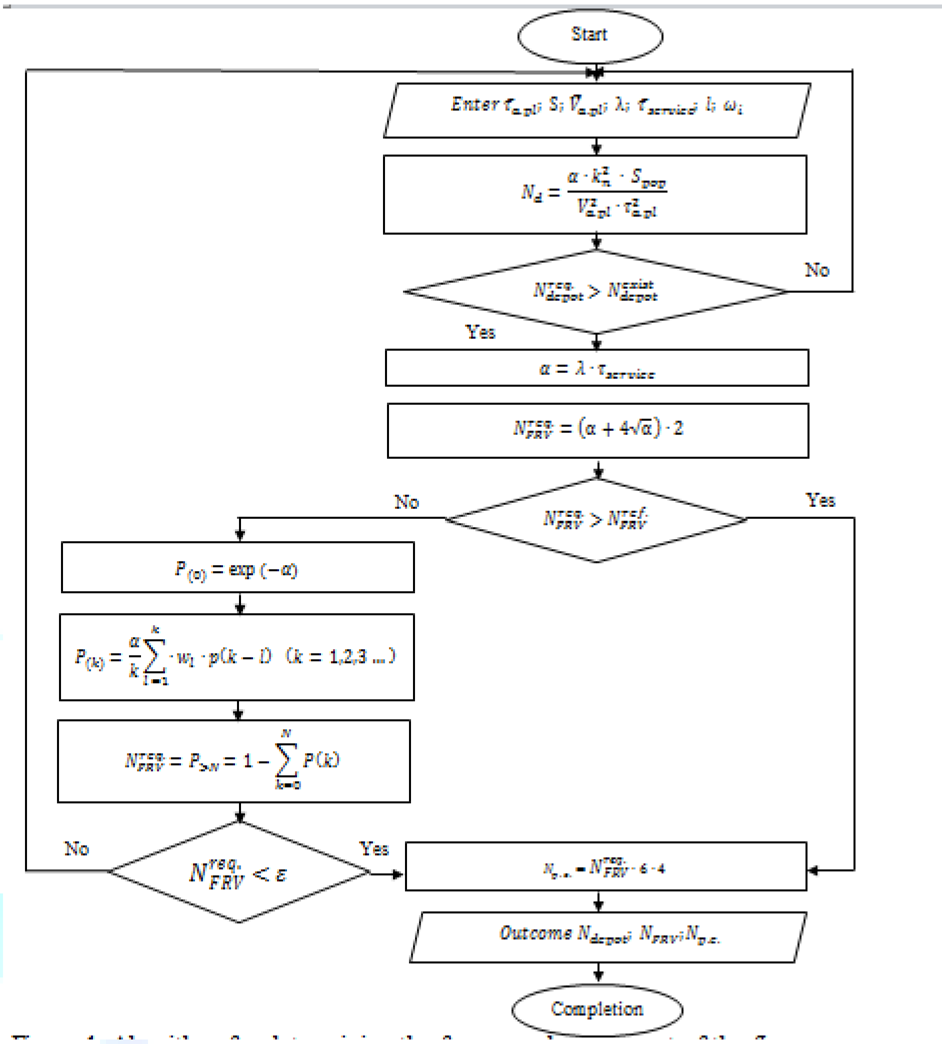

Figure 1. Algorithm for determining the forces and equipment of the fire-rescue service garrison

$\tau_{a.pl}$ – average time of arrival of fire and rescue services to the place of call;

n_l – the number of calls of fire-rescue vehicles;

S – construction area of the territory, km^2;

V_{pl} – the average speed of the fire-rescue vehicle reaching the place of call, km/h;

l – a list of different values of the number of exits of fire-rescue vehicles on call;

ω_i – relative frequency;

λ – call flow density, call/day;

α – speed of the flow of calls, erl.;

$\tau_{service}$ – the average call-out time of fire-rescue services per year, minutes;

N_{depot} – the number of fire-rescue depots;

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N_{FRV} – number of fire-rescue vehicles;

$N_{p.c.}$ – number of personal content;

P_k –the possibility of rapid employment of k fire-rescue vehicles of the same type at the same time;

ε – the risk of a situation where more than N cars are needed;

$P_{>N}$ – the probability that more than N vehicles will be required at the same time than the ones available in the garrison.

3. In the third stage the required number of fire-rescue vehicles is determined in three ways [1, 2, 4]:

the first method the number of fire-rescue vehicles is determined in the combat account for each depot;

the second method (estimator) – the simultaneous occupancy of the fire-rescue vehicle calculated according to the given speed of the call flow is taken into account, $\alpha = \lambda \cdot \tau_{service}$ erl.;

the third method the probability of N fire-rescue units being busy $P_{>N}$ in the (main) city takes into account the P_j number of j fire-rescue units that are busy at the same time and the critical value ε of the rejection probability.

At this stage, the determination of the necessary number of fire-rescue service units is based on the theory of public service. The public service system is divided into the following types according to a number of symptoms. The public service system is divided by channels into single-channel (if the service has one channel) and n multi-channel (if there are a number of channels $n \geq 2$) systems.

The public service system is divided into three classes according to the order of service: refusal is introduced - queue (waiting) is not introduced; non-repudiation - a queue (waiting) is introduced; are divided into mixed public service systems with non-repudiation and limited queue length or waiting time.

Denial implemented - if a new call arrives at a time when all channels of the public service system without queue (waiting) are busy with call service, it will refuse to serve this call. The call leaves the system unserviced. Denial one of the important characteristics for public service systems where denial is implemented is the probability of denial of service to a call. For this reason, telephone exchanges, most emergency services, and emergency services are included in the public service system with a denial-of-service system in place.

If we focus on the public service systems in the field of fire safety, the fire-rescue service garrison in a certain area, the fire-rescue units with several combat units, the multi-channel public service system, and a separate fire-rescue post protecting premises, fire-rescue units consisting of one combat unit will be included in the single-channel mass service system with the introduction of rejection.

4. In the fourth stage the required number of employees $N_{p.c.}$ is determined from the calculation of one fire-rescue vehicle - 6 employees. The received data is multiplied by the number of shifts on duty, in this case it is multiplied by 3 or 4 depending on the number of shifts. Special techniques are added as needed. In the same way, other main and special fire-rescue vehicles, employees of fire-rescue depots, etc. are determined.

In our example, the area of the protected area is 220 km^2, that is $S_{common} = S_{construction} = 81\ \text{km}^2$, we take the coefficient $k_n = 1.3$. The average time of arrival of fire and rescue services to the place of call is $\bar{\tau}_{a.pl} = 6.1$ minutes, the speed of arrival of fire and rescue vehicles is $V_{pl} = 51\ \text{km/h}, \alpha = 0.3$.

The first method the number of fire-rescue depots $N_{FRV}^{min} = N_{depot}$ required for the area, depending on the average

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time of arrival of fire-rescue vehicles to the place of call and the average speed of movement, which we have calculated according to the following formula developed by professor N.N Brushlinsky:

$$N_{depot} = \frac{\alpha \cdot k_n^2 \cdot S_{city}}{V_{a.pl}^2 \cdot \tau_{a.pl}^2} \qquad (1)$$

By putting the previously obtained values:

$$N_{depot} = \frac{0{,}3 \cdot 1{,}3^2 \cdot 220}{0{,}85^2 \cdot 6{,}1^2} = 4\, depots.$$

Thus, for the area selected according to the first method, 4 depots and 4 fire-rescue vehicles are needed, respectively.

To the second method according to (predictor) $\alpha = \lambda \cdot \tau_{service}$, α - the speed of the flow of given calls, erl. A $N_{FRV} = (\alpha + 4\sqrt{\alpha}) \cdot 2 = (0{,}04 + 4\sqrt{0{,}04}) \cdot 2 = 3$ fire-rescue vehicle is required for the area.

In the rapid operation of fire-rescue service units, a situation $(> N)$ may arise when fire-rescue vehicles that exceed their initial number serve calls at the same time.

To the third method according to this, the probability $NP(> N)$ that the given number of fire-rescue vehicles will not be sufficient to serve calls in the studied area at any time is calculated according to the following formula.

$$P(> N) = 1 - P(\leq N) = 1 - \sum_{k=0}^{N} P(k) \qquad (N = 0,1,2,3,\ldots), \qquad (2)$$

The expected total duration $T(> N)$ for the observation period $T_{observ.}$ of the number of fire-rescue vehicles N engaged in simultaneously serving calls in the protected area exceeding the initially given value (that is, with the involvement of additional fire-rescue vehicles) is estimated according to the following formula:

$$T(> N) = T_{observ.} \cdot P(> N) = T_{observ.} - \sum_{k=0}^{N} T(k) \qquad (N = 0,1,2,\ldots) \qquad (3)$$

The frequency of refusals $f_{refusal}(N)$ (both full and partial) in the number of fire-rescue vehicles N provided in the service of calls in the protected area is calculated according to the following formula:

$$f_{refusal}(N) = \lambda - \sum_{k=1}^{N} f(k) = f_{refusal}(N-1) - f(N) \quad (N = 0,1,2,3,\ldots) \qquad (4)$$

The frequency of complete refusals $f_{c.refusal}(N)$ in the number of fire-rescue vehicles N provided in the service of calls in the protected area is calculated according to the following formula:

$$f_{c.refusal}(N) = \lambda \cdot P(> (N-1)) = \lambda \cdot (1 - \sum_{k=0}^{N-1} P(k)) \quad (N = 1,2,3,\ldots) \qquad (5)$$

The frequency of partial refusals $f_{p.refusal}(N)$ in the number of fire-rescue vehicles N provided for service calls in the protected area is calculated according to the following formula:

$$f_{p.refusal}(N) = f_{p.refusal}(N) - f_{c.refusal}(N) \quad (N = 0,1,2,3,\ldots) \qquad (6)$$

Calculation results to justify the number of fire-rescue vehicles required for the fire-rescue service for the area are presented in the table below.

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Estimated values of criteria for justifying the number of emergency units of fire and rescue services in the city

Number of FRV N	The possibility of lack of FRV $P(>N)$	Total duration of time $T(>N)$, hour	Frequency of refusals, circumstances		
			$f_{refusal}(N)$	$f_{c.refusal}(N)$	$f_{p.refusal}(N)$
0	0.038749	339.44	82	82	0
1	0.013269	116.24	29.13	3.18	25.95
2	0.006445	56,46	14.27	0.39	13.89
3	0.001638	14.35	3.93	0.09	3.84
4	0.000101	0.89	0.43	0.01	0.42
5	0.000031	0.27	0.13	0.00	0.13
6	0.000009	0.08	0.04	0.00	0.04
7	0.000001	0.01	0.01	0.00	0.01
8	0.000000	0.00	0.00	0.00	0.00

As can be seen from the table, when the number of fire rescue vehicles is 5, the probability of missing is $3{,}1\cdot10^{-4}$, less than $0{,}13 < 1$ refusal, complete refusal is 0, the total duration of additional units' employment with call service is 0,27 hours in the city /year = 16 minutes/year. Therefore, to ensure the fire safety of the area, 5 main fire-rescue vehicles (units) will be sufficient to serve calls in the area at the same time.

The number of personnel required for fire-rescue services is calculated according to the following formula:

$$N_{p.c.} = [N_{TT}\cdot 6 + N_L \cdot 2]\cdot N_{d.t} + (N_{FRD}\cdot N_{l.st} + N_{FRD}\cdot N_{tech.staff}) \qquad (7)$$

where: N_{FRV}– the number of fire-rescue vehicles in the department;

6 – combat calculation of one fire-rescue vehicle (TTs);

N_L – the number of ladders (the necessary number of special fire-rescue vehicles is determined in relation to the population of the regions in accordance with Table №1 of Clause №8 of "Fire-Rescue Depots and Posts" of NoUP 2.09.21-22);

2 – combat account of one driver;

$N_{d.sh.}$ – number of duty shifts (3 or 4);

N_{FRD} – the number of fire-rescue depots;

$N_{l.st}$ – leadership structure of the fire-rescue service (head of department and deputy head of department);

$N_{tech.staff}$ – technical staff of the fire-rescue service (senior technician, head of the fire-rescue service, liaison officer);

The analysis of the fire-rescue service's operational activity showed that 5 main fire-rescue units are sufficient to serve the calls at the same time. If the average arrival time of fire-rescue units $\bar{\tau}_{a.pl} = 6.1$ minutes, then the city should have 4 depots.

$$N_{p.c} = [5\cdot 6 + 1\cdot 2]\cdot 3 + ((4\cdot 1) + (4\cdot 3)) = 96 + 4 + 12 = 112\, person\, p.c.$$

Thus, to ensure the operation of 4 fire-rescue services (depots) with 5 main fire-rescue vehicles (TTs) and 1 ladder

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driver (L) for the protected area, 96 fire-rescuers, 4 leaders, 12 total of 112 technical personnel will be required.

In summary, determination of depots, forces and means necessary for fire-rescue services in ensuring fire safety of residential areas andthe requirements of existing regulatory documents in the organizational design of fire-rescue services serves to solve economic difficulties that may arise in practical application.

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