DEVELOPMENT OF PRINCIPLES OF EFFECTIVENESS EVALUATION OF FIRE–ALARM SIGNALING SYSTEMS

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ABSTRACT

Principles are described for evaluating the effectiveness of an automated fire–alarm signaling system, in contrast to visual detection of fires.

The main aim that is pursued when equipping any object with a fire alarm system consists of reducing detection time and, accordingly, minimizing the period of uncontrolled fire development, before fire–fighting agents of an active fire defense are introduced. Doing so, it becomes possible to cut down material damage from the fire and, in the majority of cases, to avoid disastrous consequences.

The effectiveness of a fire–alarm signaling system (FASS) is defined by its ability to contribute to achieving gain with the least expenditure in all allowable exposure ranges.

It is obvious that early fire detection itself, with FASS functioning irreproachably, is not by itself a guarantee of quick extinguishing of a fire. The arriving signal must be received, processed, and sent to the fire command, whose watch must arrive at the object, detect the fire, and put it out. In particular cases, variations of this scheme are possible without changing its essence; for example, automatic signal transmission to the fire command, or extinguishing of the fire by an object's own personnel.

From what is said above, it follows that, in the conception being worked out of quantitative estimates of FASS effectiveness, one should take into consideration not only technical parameters of the system's elements that guarantee the fulfillment of its main task, but also the characteristics of defended objects having an influence on fire development and the level of fire–fighting measures.

Among the system's parameters subject to exploration are the following: the fire–alarm sensitivity; the time of signal processing with a receiving and monitoring device; and the availability of direct transmission of a signal to fire command.

Since the fire start time depends on the exactness of pointing out the fire location, the number of addresses in the system needs to be included, too, as one of the indicators producing an effect on its effectiveness. On the other hand, the criterion being worked out should take into account the diminution of FASS effectiveness with the growth of the frequency of false signals produced by the system that do not accord with the state of the checked object.

The criterion sought for is to provide an opportunity to bring together various system characteristics and a defended object (not connected with each other, and having different quantitative dimensions) into a single integral indicator characterizing the object's protection by means of fire signaling.

As at any object, defended lodgings are different from the point of view of their fire security. So, when using the same hardware components of automatic detection, the expected lowering of fire loss appears to be different. Therefore, the quantitative indices of FASS effectiveness should be determined separately for every defended apartment, and after that be generalized while passing on to a real object with an arbitrary number of defended apartments.

Bringing together all the examined parameters into economic indices gives us a chance to make proper generalizations.

In the majority of cases one may choose as a criterion of FASS effectiveness the relationship between the expected damage decrease from a probable fire and the object's required equipment expenditure for fire–alarm signaling (all of the economic indices used in the subsequent calculations are given by the year of operation):

$$W = (m_b - m_c)/M_c \qquad (1)$$

where m_b is the value of expected fire damage in the case of visual detection (we (assume no additional expenses to reduce the time of visual detection are made); m_c is the expected damage when using fire–alarm signaling; and M_c is the expenditure connected with equipping and operating FASS for an object.

In general, in the numerator of the relationship (1), not only direct, but also indirect, losses have to be considered. However, considering early fire detection and liquidation to lead to minimizing both direct and, all the more, indirect damage, the indirect losses may be taken into account only in quantity m_b.

However, the possibility of applying the offered criterion is limited by the fact that for a number of defense objects the fire hazard is associated not only with material losses. Thus, at objects of mass peoples' residence, prolonged uncontrolled fire development (for instance, in zones of escape routes) may result in terrible consequences connected with human victims. Besides that, in a number of cases, late fire detection in one lodging may result in loss of the whole defended object. In fact, the question is one of a substantial rise in indirect damage from a fire with respect to direct damage.

When realizing fire–protection measures at an object of this sort, the question of the material values of directly defended apartments becomes a secondary one. In such cases, one can usually determine an allowable time limit of detection, T_{pr}, which is specified proceeding from the concrete peculiarities of an object of defense. Exceeding the time limit is fraught with grave or extremely grave consequences.

In conformity with such an object of protection, it is possible to perfect criterion (1), keeping in mind the following prerequisites. As long as the prescribed goal (the limitation of detection time) may be achieved at various material expenses, the economic effect is defined as the expenditure difference that is necessary for promoting discovery during a time period not exceeding T_{pr}, when using fire–alarm signaling versus visual detection:

$$M_c = M_o + M_{pm} + M_{to} + M_{oa} \qquad (2)$$

where M_o is the cost of the fire–alarm signaling apparatus and components; M_{pm} is the cost of design work and assembly; M_{to} is the cost of maintenance and repair; and M_{oa} is the material damage done to the consumer in case of apparatus failure.

For the practical application of the suggested quantitative effectiveness criterion of fire–alarm signaling, it is necessary to offer calculation principles, being not evident, of some parameters forming parts of expressions (1) and (2). Possible definitions of these parameters, using available data, are presented below.

First, let us define the expected damage reduction owed to using fire–alarm signaling: $(m_b - m_c)$. For simplicity, a conditional lodging with a common nature of combustible load and a uniform distribution of material values over the area is investigated (apartment index i is omitted). The time reading begins from the origin of the site for ignition.

The maximal time to the start of putting out the fire, T_{nt}, is:

$$T_{nt} = T_o + T_{pp} + T_{br} + T_{po} \qquad (3)$$

where T_o is the maximal time of fire detection at the object (from the start of burning till the fire detector's operation); T_{pp} is the time of decision-making by the receiving and monitoring desk, and signal transmission to the duty command; T_{br} is the time of moving to the object, and combat deployment of the fire protection unit; and T_{po} is the time of searching the site for the hotbed.

The difference in values, T_{nt}, obtained from expression (3) when automatic versus visual discovery happens, may reach some dozens of minutes.

To make calculations it is necessary to know the principle of assigning the quantities T_{ntc} and T_{ntv}, where T_{ntv} is the time of putting fire–fighting agents into operation upon visual discovery, and T_{ntc} is the time of putting them into operation upon automatic discovery. The value of T_{ntv} is computed according to formula (3) after substituting T_o for T_{ov}, the maximal time of visual detection. The last quantity may be obtained either from available statistical data, or on the basis of analysis of the protected lodging or an adjacent one. The search time of the site for ignition, T_{po}, is determined by the number of apartments protected within one plume, and also by the average time to access and survey one apartment, specified for concrete groups of apartments. For simplicity, T_{po} may be defined with the expression:

$$T_{po} = \alpha(N - 1) + \beta \qquad (4a)$$

where N is the number of detectors in the plume; α is the average time of one apartment's survey; and β is the time of access to the group of apartments defended within one plume.

For address systems (or in the case of plume defense of only one apartment):

$$T_{po} = \beta \qquad (4b)$$

So, from the parameters used in the value calculations, $(m_b - m_c)$, uncertainty concerning the assignment of quantity T_o, the time of fire discovery when using FASS at the object, does not vanish.

In view of the diversity of possible alternatives of fire development, it seems to us to be unrealistic to give an accurate forecast of the nature of change in factors accompanying burning. One of the possible ways to formalize the task consists of hypothetically substituting for the real hotbed site a standard site whose composition is similar to the combustible load of the defended apartment. Supposing that the location of ignition is the furthest point in an apartment from the nearest fire detector, one may determine the maximal time of reaching the operation threshold of the fire detector with the parameter being inspected, and accordingly, the maximal time of discovery. To eliminate the subjectivity of such an approach when choosing a standard, it is appropriate to use sites for ignition similar to those determined by the European Standard, EN–54 (part 9), for testing fire detectors.

To obtain the values of T_o, it is necessary to know the operational thresholds of the fire detectors chosen for setting up in the apartment. For smoke detectors, that is the threshold smoke concentration, C_{por}, at which fire–detector operation occurs. For heat detectors, it is the threshold temperature, T_{por}, or the rate of its rise. Assuming that the probable site for ignition may be situated at at an arbitrary point of the apartment, when determining the time of discovery we must set values of R_{max}, from the arbitrary point of the object defended to the nearest fire detector.

Then, solution of the equations:

$$C_{TFi}(R_{max},h,t) = C_{por} \quad (5)$$

and

$$\grave{a}_{TFj}(R_{max},h,t) = T_{por} \quad (6)$$

relative to t (where h is the height of the apartment) yields quantity T_o, the maximal discovery time of the checked site for fire TFi, that may be applied in expression (3). It should be noted once more that T_o is the time of discovery of the least favorably located of the checked ignition sites. The real time may differ from T_o in either direction.

The character of the time relations of temperature and smoke concentration in the apartment, (5) and (6), when the checked ignition sites are burning, may be specified either by computing, using a mathematical model of the initial fire stages, or on the basis of regression analysis of the experimental data, obtained in the process of experimenting on the ignition test sites.

In order to define the represented cost of apparatus failure introduced into formula (2), M_{oa}, it is necessary to elucidate the frequency and behaviour of the fault system. Since a legitimate signal is always present in the FASS plume at a background disturbance exerting an effect on the primary transducers or the data channels, the decision made by the system is of a probabilistic character.

The exhaustive list of feasible states of a non–address system is given in a table.

In order to evaluate operational effectiveness, it is necessary to determine both the principal possibility of realization of different states, A_{ik}, and the conditional probability, P_{ik}, of a desk's being in mode i at action k.

It is evident that failure omission and fire omission lead to various material losses.

Introducing the notion of cost, r_{ik}, of every examined consequence of the situation (the cost of right solutions, $r_{11} = r_{22} = r_{33} = 0$), and taking into account *a priori* probabilities of every signal appearance, P_k, for a typical concrete object, we obtain the expected average cost of unsatisfactory operation of the fire alarm signaling system.

Knowing the quantity, T_{pr}, it is possible to define the required level of expenditure to ensure such detection time without applying a fire alarm signaling system, at the expense of organizing a permanent watch or periodic rotations.

It is necessary to survey every apartment, i, not less frequently than time interval, T_{pr}. Having implemented this requirement, the following condition should be carried out:

$$H \times \delta(t_o) \leq \max(T_{pr}), \quad (7)$$

where H is the average number of apartments supervised by one man, and $\delta(t_o)$ is the average time of surveying one apartment.

The suggested conception defines a perspective direction for developing ideas of FASS effectiveness. The expediency of conducting appropriate investigations in the given direction is beyond any doubt. *A priori* estimation of the fire alarm signaling system allows us to optimize the solutions to problems of apparatus development, an object's equipment with the fire alarm signaling system, or its modernization.

It needs to be noted that the level of an object's fire protection is characterized by a number of indices, FASS effectiveness being only one of them.

It is no less important to secure constructive fire fighting protection, and to solve tasks appearing in the field of fire prevention. But, the possibility of independent effectiveness appraisal by means of the fire alarm signaling system only arises from the fact that, when FASS functions normally, a fire is discovered and liquidated at an early stage, while developing within the limits of one apartment, until the behavior of its development starts influencing the constructive defense. Therefore, the quantitative effectiveness index of fire alarm signaling systems is independently significant; and, at the same time, it may be applied to the complex estimate of the level of an object's fire fighting defense.