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Theoretical Basis for Designing Integrated Security Systems of Potentially Hazardous Facilities

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Abstract

The articles offers theoretical basis for designing integrated security systems of potentially hazardous facilities that include two design stages: external design (system layout definition) and internal design (design of the features of structural-and-parametric and operational properties of the system). A flow chart of system requirements formation is considered. The main stages of the system life cycle are detailed. The concept of solvability of a system design objective is introduced.

Keywords: potentially hazardous facility, integrated security system, design, structure, system layout, system life cycle, systematic approach, synthesis, decision-making.

INTRODUCTION

In recent years, there is a world tendency to increase in the amount and scale of consequences of natural and man-made emergency situations including at explosive, radiation, chemical, biological and other hazardous facilities. The sources emergency events include natural hazards, natural risks arising in the course of economic activity, acts of terrorism, as well as major industrial disasters and catastrophes.

The solution of the security issue at these facilities is complicated by its omnitude, as it requires considering various aspects in complex [1]: socio-economic, organizational, technical, management, information, human, psychological and other aspects [2]. Trying to jointly address these problems requires, in its turn, the development of new concepts using the latest achievements of science [3]. Development of theoretical bases and implementation of multi-step integrated security systems at critical, potentially hazardous facilities as part of daily activities in case of threatening or occurring emergency is one of the most important scientific challenges [4-6].

PROBLEM STATEMENT

The integrated security systems (ISS) of potentially hazardous facilities (PHF) shall be reviewed as a complex dynamic facility. The characteristics and properties of the systems as control facilities, the control arrangement procedure shall be based on modeling. The methodology of system research of complex dynamic systems and control in case of threats and emergencies is characterized by uncertainty typical of emergencies and requires timely decision-making taking into account facility, municipal and regional aspects.

The effectiveness of use of such systems is essentially defined by a possibility to dynamically change their structures and control strategy, which is a time function and depends on qualification of decision-making persons (DMP) and is based on one of possible structure alternatives [7-9] chosen under the conditions of current limitations for the system resources as well as under the conditions of technical possibilities of the separate elements and subsystems included in its structure (fig.1).

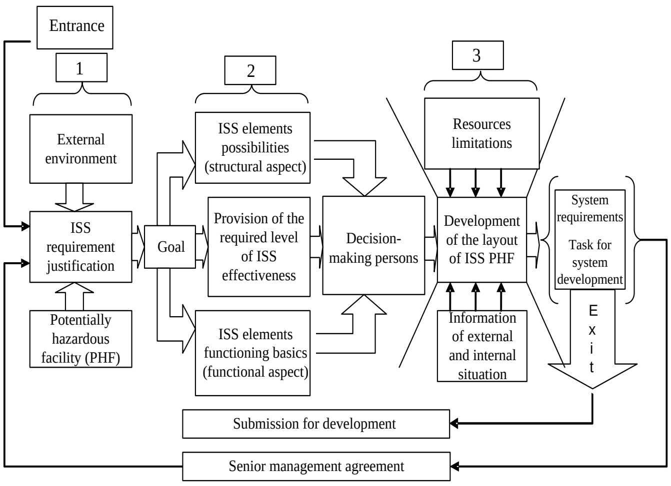

Figure 1: Flow chart of formation of system requirements to ISS PHF

SOLUTION TECHNIQUES

Let’s review the issue of creation of ISS PHF suggesting facility follow-up during all the steps of its life cycle (LC), whose components are given in figure 2. The steps are a complete cycle where system functioning conditions at the actual use step are the basis for the step of system layout selection. An incorrect decision made at the step of system layout selection is tantamount to the further creation of irrational system in general. System layout definition allows for selection of the ways to solve the problem, for which the system is established [10].

We will consider a *system layout* to be the target, basic characteristics of the system and relations between its elements that define system possibilities and the mechanisms to implement these possibilities.

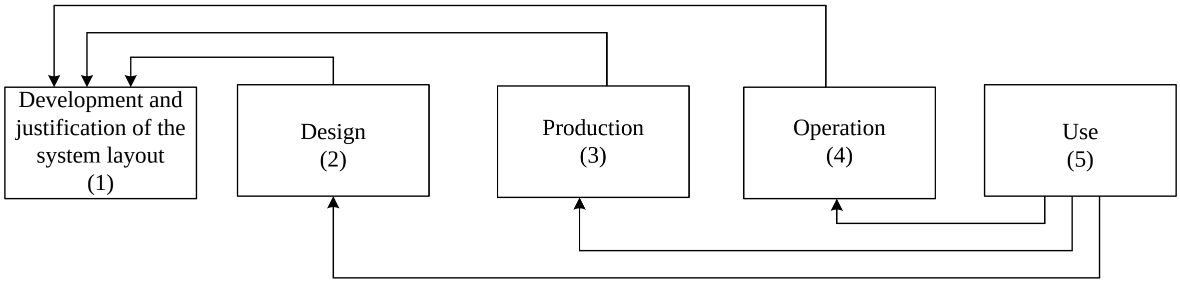

Figure 2: The main stages of the system life cycle

Thus, system design should be based on two-step design, that is external design (system layout definition) and internal design (design of the features of structural-and-parametric and operational properties of the system) [11,12].

Besides, any errors made at the step of system layout selection lead to uselessness of the system as a whole; any errors in the internal design of its elements result in uselessness of the system due to irrationality of its parameters; errors in production, operation and direct use reduce its effectiveness. At every stage of the system LC, there are specific approaches, methods and models for defining the relevant rational solutions.

The chosen line of research includes issue formalization, relevant goals statement and development of the techniques used to define the possibility of existence of a design solution [13-15]. Note that in general, this refers to an acceptable design solution, as obtaining an optimal solution is determined by the optimal structure, composition, management, their interaction, etc., which is largely a time category and is forecasted. Since the pre-design stage of the ISS LC is implemented in the face of considerable informational uncertainty [16,17] and is based on fuzzy expert suggestions, and includes examination of possible facility development, which is forecasted, the use of set-theoretic methods and uncertainty approach methods is quite relevant and well-founded.

ISS PHF design shall rely on new ideas and and concepts that reflect not only the up-to-date level of science and technology, but also completely new principles of design and organization of technical, organizational and production systems [7,18]. In the general setting, the development of methodology for supporting ISS PHF at the LC stages is complicated by considerable complexity of the overall issue, need to process and analyze large amounts of information, uncertainty and lack of completeness of the source data. The open nature of issues that arise during LC and the associated person's freedom of choice, determine the requirements toe organization of the ISS design process implemented based on the systemic approach.

The area of ISS PHF description includes the environment (natural and artificial), structure and element basis [19]. The issues defined by these components accompany ISS PHF at all stages of LC.

1. First stage of LC ISS PHF– ***development and justification of the system layout*** – starts from carrying out scientific research according to the "need recognition to goal setting” plan and estimating its implementation (fig.3).

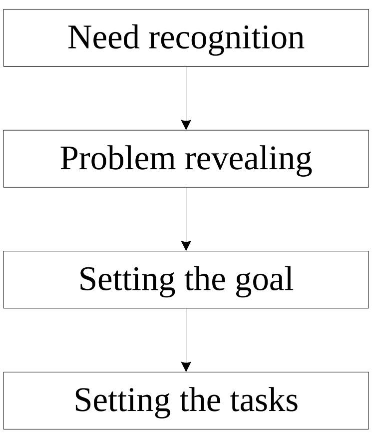

Figure. 3: Scientific research implementation plan

The reviewed stage is a preparation stage for internal design, and the data on its results and intermediate data are used at the stage of internal design planning. The core of the research lies in defining the possibility of existence of the design solution in compliance with a definite goal.

For Z projection: $X \to Y$ original data X to the result Y, the following limitations are imposed

$$\xi(Z) \in \Theta_1, \zeta(Z) \in \Theta_1, \varsigma(Z) \in \Theta_1, \quad (1)$$

where ξ is environment limitations function, ζ is structure limitations function, ς is element set limitation function, herewith the resolvability of ISS PHF creation task requires meeting the following condition:

$$\Theta_1 \cap \Theta_2 \cap \Theta_3 \neq \varnothing. \quad (2)$$

Note that $\forall i \in \{1,2,3\}$ $\Theta_i = \Theta_i^1 \cup \Theta_i^2$ where Θ_i^1 is scope of limitations imposed on the research system, Θ_i^2 – on ISS PHF as on the research subject.

Lets assume that the designed system is currently characterized with a generalized parameter q. The numerical value of its i-th component at the time moment t – $q_i(t)$ characterizes i-th systemic and internal attribute, $t \in [t_1, t_2]$ where period $[t_1, t_2]$ defines the time of system operation. Then, the state of ISS PHF can be reviewed as a point in a phase field of systemic attributes

$$Q = (Q_1, Q_2, \ldots, Q_n). \quad (3)$$

If the systemic attributes are equal, (3) can include one of them if $Q_i = f(Q_j)$ where f is some function, then (3) shall include Q_i.

Thus, normalizing the resulting vector of orthogonal systemic attributes Q, we define an orthonormal basis for the field of ISS PHF layout existence. Customer influence on the development and justification of ISS PHF layout lies in determining the requirements for the research process, as well as in distributing the system resources. At the research stage, a possibility of implementation of the strategy [20] $S \in C_s$ by the leading person or supervising organization shall be provided for ISS PHF where C_s is a set of management strategies (final), and, as every strategy S is implemented through selected structure $c \in C_c$ where C_c is not an empty, final set of alternative structures, it is necessary to foresee a variable controlled structure [8,9] defining the existence of function

$$D: C_c \to R, \quad (4)$$

where $c \in C_c$, and R is the result of ISS PHF operation. At the research stage, a possibility to meet the requirements to operation process and ISS PHF development perspective shall be taken into account.

2. The ***design*** stage comes next that can be reviewed as an object-oriented process of transforming material (M), energy (E) and information (I) resources into a design (system design) or, officially, as existence of function [21]

$$P : \langle M, E, I \rangle \to R, \quad (5)$$

where R is the design concept.

Let's review the resolvability of the system design objective (Ω) as existence of the system layout that suggests possibility to obtain a concept that is officially expressed with the following definition.

Definition. Problem Ω is solvable <=> $\exists R$ is the design concept with $\Psi(R) \in \Xi$ where Ψ is a generalized criterial function, Ξ is the area defined by the specified requirements.

If problem Ω is solvable, it is necessary to proceed with systemic designing. Designing takes into account the complex system as an ordered set of objects that enable functioning of the system as a single whole during their interaction. There two approaches to solving this problem: the first one suggests paying central attention to designing process, its arrangement, its logic structure, and the second one that is based on dividing the problem domain into classes and objects as well as on their operation as a set of reactions to the influence of the environment. Optimal implementation of the suggested approaches gives complex structures by using decomposition, abstraction and hierarchy methods [22, 23].

Both in the process of development research and justification of the system layout and during the very system designing, ISS PHF acts as a passive category whose operation is described in models. Reviewing ISS PHF as a complete whole, the following basic models can be mentioned:

– structures (M_c) describing the “part – whole” relation and presented with set-theoretical combining operation

$$A = \bigcup_{i \in I} A_i \quad (6)$$

where I is index set, A_i the elements of A;

– operation (M_f) describing the procedure of goal achievement by the facility that is carried out by its components and represented with the functions

$$F_1: \langle P, C_c^t, C_s^t, X^{t-1} \rangle \to X^t, \quad (7)$$

$$F_2: \langle P, C_c^t, C_s^t, X^{t-1} \rangle \to Y^t, \quad (8)$$

where t is the moment of ISS PHF operation period, , P is the vectors of applied problems that is shall solve, C_c^t is its structure at moment t, C_s^t is the management strategy, X^t is ISS PHF state, Y^t its result at moment t;

– development (M_p) describing adaptive processes of ISS PHF in the environment through the function

$$F_3 :< E_z^n, P_r^n > \to < E_e^n, E_f^n, E_a^n, R >, \qquad (9)$$

where E_z^n and P_r^n are new objectives and processes for reaching these objectives that, respectively, suggest availability of such elements E_e^n in the ISS PHF structure that are able to accept new functions E_f^n and to promote development of new unconventional solutions R through new operations E_a^n. Sets E_z^n and P_r^n are fuzzy categories due to their fuzziness at the design stage and due to fuzziness of the time interval between suggestion of possible implementation and implementation E_z^n defined by the function $\xi(Z)$. Evaluation of such possibility and its characteristics are defined at the stage of investigation of task Ω solvability. Reviewing the forecasted operation of ISS PHF, let's indicate Q^0 to be the field of states of ISS PHF. Then, it is possible to specify the function existence

$$< E_z^n, P_r^n > \to Q^0. \qquad (10)$$

Field Q^0 has three components: $Q_c^0, Q_p^0. Q_n^0$

where Q_c^0 are states definitely known a priori;

Q_p^0 are components whose probability distribution is known;

Q_n^0 are components whose values can be suggested by experts.

Consequently, Q_c^0 does not depend on $\xi(Z)$. For Q_p^0, function $\xi(Z)$ can be officially reviewed as a density of probability of state Q_p^0 of ISS PHF. Taking into account that components Q_n^0 are fuzzy sets, $\xi(Z)$ is a multidimensional membership function [24-27], the following relation is obtained:

$$Q_n^0 \leftrightarrow \Psi(\xi(Z)), \qquad (11)$$

where

$$\Psi(\xi(Z)) = \left\{ q_n^m \in Q_n^0 \middle| \xi(q_n^m) = \max_{q_n \in Q_n^0} \xi(q_n) \right\}. \qquad (12)$$

The principal development model looks like:

$$F_3 :< E_z^n, P_r^n > \to Q^0 = Q^0(C, M\ \xi(Z), \Phi(\xi(Z))), \quad (13)$$

where C are system state components being constants.

The systemic designing is a logical unity of three procedures [10, 11, 18]:

– synthesis;

– analysis;

– choice and decision-making.

Their iterational implementation allows to reduce uncertainty at initial stages using predicted data for this purpose.

3. The **production** stage continues the LC of ISS PHF and defines implementation of the transformation

$$< \chi(R), R, R_e \quad > \to R_i, \qquad (14)$$

where $x(R) = \begin{cases} 1, & \text{if problem } \Omega \text{ is solvable} \\ 0, & \text{if problem } \Omega \text{ is not solvable} \end{cases}$

R_e is resources required to create ISS PHF, R_i is the result of the production stage.

In (14), $\chi(R)$ can be substituted by α –the measure of possible existence of R.

If the amount of resource R_e is excess, the task of ISS PHF creation has optimization character.

Optimization of ISS PHF creation is implemented at 4 levels: economical (E), organizational (O), technological (T_o) and technical (T_u), which is formally represented with a search $e_k \in E$, $e_k \in O$, $t_o \in T_o$, $t_u \in T_u$,

$$K\ (e_k, o_r, t_o, t_u) \to opt, \qquad (15)$$

E, O, T_o, T_u are optimization levels, K is integral criterial function.

4. **Operation** is another stage of LC of ISS PHF. Its components include the processes of use, reaching final goal, modernization of ISS PHF. Let's formally represent the operation stage as implementation of the function

$$< \chi(R), R, \Xi, R_e, V_b, V_r, I, P_r > \to Y, \qquad (16)$$

if limitations (1), (2) are met. In (16), V_r and V_b are the rate of use and recovery of resources, accordingly, I – data flows, P_r – requirements to system operation.

CONCLUSION

Every other stage of LC of ISS PHF depends on the results of investigation of solvability of the general problem Ω. Any solutions obtained at previous LC stages can be detailed after implementation of the next ones. The reversal mechanism of ISS PHF follow-up at LC stages is not of a general but rather of a local character, which is determined by significant financial investments and possible acceptable adjustment of individual subsystems only. Only the initial step is omitted from this iterational scheme. Iterational influence cannot directly affect the main result of investigating the possibility to reach the design solution, which determines its singular importance.

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