Risk Modelling

Application of Scenario Assessment in Estimation, Regulation and Management of Risks Induced by Critical Facilities

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ABSTRACT

Modern society cannot exist without stable and reliable critical facilities (CFs), such as transportation facilities, nuclear and thermal power stations, hydro engineering facilities, water and gas supply systems, telecommunication and cyber systems, chemical, metallurgical, and oil refinery plants, etc. These facilities are critical in terms of ensuring life support of population and sustainable economic development. The functioning of critical facilities is connected with storing, conversion, and transportation of huge amounts of energy. The unauthorized release of energy at a CF may cause disastrous consequences and trigger cascading failures in the CF and other interrelated facilities and infrastructures.

Critical facilities have a complex structure and are characterized by complicated behaviour and interaction between their components. Severe uncertainties related to natural variability of system parameters environmental conditions, and external impacts, as well as uncertainties caused by the lack of knowledge about the system and various types of human errors are inherent in CFs. Due to this high level of uncertainty the CFs performance should be carried out in a probabilistic formulation using branched scenario trees. The list of possible scenarios includes scenarios of normal operation as well as catastrophic ones. In this regard, operation of critical facilities becomes impossible without the risk assessment, the development of rational criteria for the acceptability of risks, and procedures for reducing risks to levels that society is ready to accept in the view of the benefits provided by CFs.

According to the traditional risk assessment model risk is considered to be a function of threat T, vulnerability V and consequences C: $R=f(T,V,C)$. Here threat is defined as the probability of the hazardous initiating event (component failure, extreme external impact) that can occur in CF: $T=P(IE)$, vulnerability is estimated as conditional probability of system's failure given the initiating event occurs: $V=P(F|IE)$, and consequences are defined as expected losses that occur as a result of the initiating event and subsequent system failure: $C=E(U|IE, F)$. Then the risk index is determined by the Eq. (1):

$$R = P(IE) \cdot P(F \mid EI) \cdot E(U \mid EI, F) \tag{1}$$

For critical facilities that (due to their complex nature and behaviour) are subjected to multiple threats and multiple failure scenarios, risk assessment implies assessment of a scenario tree (Figure 1). This is being done using graph models called scenario trees. The system is designed to fulfil the so-called success scenario S_0 (i.e. a transition from its initial state IS to the designed end state ES_0). Since any failure scenario S_* presents a deviation from the success scenario S_0 that corresponds to the successful functioning of the CIF, the scenario S_* must have a disturbance point at which an extreme initiating event, (IE_*), occurs. Each IE gives rise to a branch of a scenario tree that has a corresponding set of scenarios S_i that ends with an end state (ES_i). In this case one can get a similar risk index using matrix expression:

$$R = \underbrace{\{P(IE_1);P(IE_2);...;P(IE_n)\}}_{Threat\ T} \times \underbrace{\begin{bmatrix} P[ES_1|IE_1] & P[ES_2|IE_1] & \cdots & P[ES_m|IE_1] \\ P[ES_1|IE_2] & P[ES_2|IE_2] & \cdots & P[ES_m|IE_2] \\ & ... & & \\ P[ES_1|IE_n] & P[ES_2|IE_n] & \cdots & P[ES_m|IE_n] \end{bmatrix}}_{Vulnerability\ \mathbf{V}} \times \underbrace{\begin{Bmatrix} U_{ES_1} \\ U_{ES_2} \\ ... \\ U_{ES_m} \end{Bmatrix}}_{Consequences\ \mathbf{C}} \quad (2)$$

Eq. (1) and Eq. (2) give first order indicators of risk. They also determine three main ways of risk reduction that is to reduce threat, vulnerability and consequences.

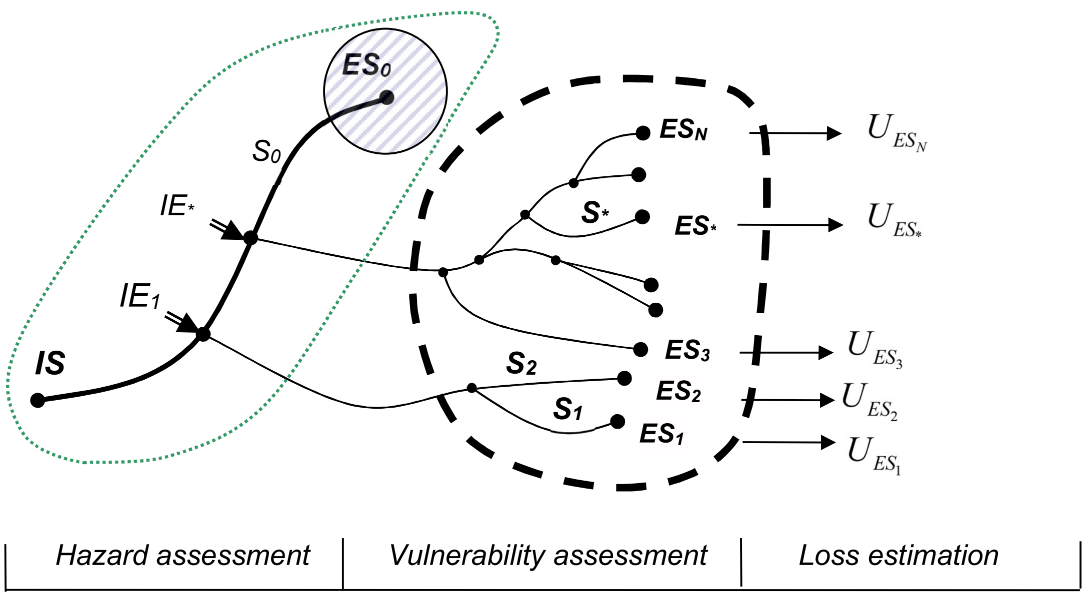

Figure 1. General risk assessment framework

A comparative assessment of risk regulation practices related to operation of critical facilities that are adopted in different countries is presented in the paper. Various risk indexes that can be used for rational decision making in design process are considered. The paper addresses the application of the ALARP principle and the principle of controlled risks in decision making regarding implementation of protection measures aimed at reduction of individual, social and economic risks induced by critical facilities.

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