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Digging to the roots: Possible examination of the SEVESO Safety Management System Using the Fault Tree Analysis Method

A gyökerek felfedezése: A SEVESO biztonsági irányítási rendszer feltételes vizsgálata hibafa-analízis módszerrel

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Introduction

The SEVESO III Directive (2012/18/EU) aims to prevent major industrial accidents involving dangerous substances and mitigate their consequences. Its practical implementation is ensured by the Safety Management System (SMS), which provides a structured framework for risk management. Although the legislation defines the content elements of the SMS, monitoring compliance is challenging for both operators and authorities, as the system's performance is influenced by numerous organizational and methodological factors. This conference paper tentatively explores the applicability of the Fault Tree Analysis (FTA) method to support the verifiability of BMS. The method, currently under scientific investigation, may enable the identification of logical relationships among factors influencing the system's operation, which could serve as a basis for developing a universally applicable, activity-independent control methodology, thereby strengthening the safety culture and reducing risks.

Bevezetés

A SEVESO III irányelv (2012/18/EU) célja a veszélyes anyagokkal kapcsolatos súlyos ipari balesetek megelőzése és következményeik enyhítése. Gyakorlati megvalósítását a Biztonságirányítási Rendszer (BÍR) biztosítja, amely strukturált keretet biztosít a kockázatkezeléshez. Bár a jogszabály meghatározza a BÍR tartalmi elemeit, annak betartásának ellenőrzése kihívást jelent mind az üzemeltetők, mind a hatóságok számára, mivel a rendszer teljesítményét számos szervezeti és módszertani tényező befolyásolja.

Ez a konferencia-közlemény feltételesen a Hibafa-elemzés (FTA) módszer alkalmazhatóságát vizsgálja a BÍR ellenőrizhetőségének támogatására. A tudományos vizsgálat alatt lévő módszer

lehetővé teheti a rendszer működését befolyásoló tényezők közötti logikai összefüggések azonosítását, ami alapul szolgálhat egy univerzálisan alkalmazható, tevékenységtől független ellenőrzési módszertan kidolgozásához, ezáltal erősítve a biztonsági kultúrát és csökkentve a kockázatokat.

Kulcsszavak: veszélyes létesítmény, veszélyes anyag, Biztonsági Irányítási Rendszer (BÍR), Hibafa-analízis (FTA), katasztrófavédelem, ipari biztonság

Keywords: dangerous installation, dangerous substance, Safety Management System (SMS), Fault Tree Analysis (FTA), disaster management, industrial safety

Fault tree analysis

Fault Tree Analysis (FTA) is a deductive, logic-based method applied to identify and assess safety risks in systems [1]. During the analysis, an undesired event—the so-called top event—is progressively decomposed, tracing back to its root causes (basic events). The interrelations and logical connections between events are represented graphically using logic gates (AND, OR), illustrating how these events lead to the occurrence of the top event. The purpose of the method is to establish a foundation for risk reduction by identifying critical failure causes and supporting subsequent planning tasks [2].

The construction of a fault tree follows a structured sequence of steps. First, the top event under investigation is defined, then its immediate causes/events are mapped. Subsequently, the events leading to the top event are further decomposed down to the basic events—which can no longer be subdivided—while the logical relationships between events are represented using logic gates. In the case of an AND gate, the simultaneous occurrence of all basic events is required for the top event to occur, whereas with an OR gate, the occurrence of any single basic event is sufficient. A major advantage of fault tree analysis is that, beyond technical failures, it is also suitable for describing deviations arising from human factors and organizational deficiencies.

The evaluation of fault tree analysis can be performed using both qualitative and quantitative approaches. In the quantitative approach, the assessment is based on the probabilities of occurrence of the basic events, the determination of which can be particularly challenging for human factors and, especially, organizational deficiencies. In contrast, the qualitative analysis focuses on identifying the most critical fault combinations by examining so-called "cut sets" composed of basic events.

Safety Management System (SMS)

The SEVESO Directive (2012/18/EU) aims to prevent major accidents and mitigate their consequences in establishments handling hazardous substances [3]. The implementation of this directive in Hungary was carried out through Government Decree 219/2011 (X. 20.) and related legislation [4, 5]. The regulatory framework prescribes the obligation to maintain a Safety Management System (SMS), ensuring the practical application of the regulatory requirements. The SMS establishes a structured framework encompassing organizational and technical measures, guaranteeing that safety objectives are not only documented but also integrated into daily operations [6].

The structure of the Safety Management System (SMS) is built upon several key elements that collectively ensure the system's effectiveness. These include [7, pp. 29-39.]:

- Organization and Personnel: Clear definition of responsibilities and roles. This includes management commitment, appropriate training, and the establishment of a safety culture.

- Identification and Assessment of Major Accident Hazards: Detecting potential hazards and conducting risk assessments are essential for prevention. This ensures that all critical points of the facility are known and manageable.
- Operational Control: Regulation and supervision of operational processes guarantee that safety requirements are effectively implemented in practice. This includes maintenance, monitoring of technological parameters, and compliance with standards.
- Management of Change and Safety Planning: Every modification -whether technological, organizational, or regulatory- must be assessed for its safety implications. Safety planning involves developing preventive and mitigation measures.
- Performance Evaluation (Monitoring): Continuous monitoring and assessment of safety performance enable early detection of deficiencies and identification of improvement opportunities.
- Audit and Review: Regular inspections and reviews ensure compliance and support the continuous improvement of the management system.

The Safety Management System (SMS) is therefore not merely a formal requirement but a fundamental tool of safety culture, integrating regulatory expectations into practical application [8, pp 5-22.].

Fault tree analysis of the safety management system (SMS)

The starting point of fault tree analysis is the definition of the top event, which in the present study is the absence or inadequacy of SMS implementation, namely "Improper implementation of the Safety Management System (SMS) in a SEVESO establishment." This formulation clearly reflects that the objective is not to identify a specific technical failure but to uncover operational deficiencies within a complex system. Defining the top event is critical because it determines the focus of the analysis and specifies which cause–effect chains need to be examined.

The next step is to identify the immediate causes/events leading to the top event. Based on the structure of the Safety Management System (SMS), these causes can be traced back to the key elements of the system and their inadequate functioning, namely, they may include the following:

- Deficiencies in organization and personnel.
- Deficiencies in risk assessment.
- Deficiencies in operational standards.
- Deficiencies in protective planning.
- Deficiencies in performance monitoring.
- Deficiencies in documentation [9, pp. 659-667.].

During the graphical representation of the identified events in a fault tree, the relationships between individual events are expressed using logical gates (AND, OR). In the case of an AND gate, the simultaneous occurrence of multiple conditions is required for the output event to take place, whereas in the case of an OR gate, the fulfillment of a single condition is sufficient. During the analysis, the recording of initiating events continues down to the basic events, which can no longer be decomposed and directly contribute to the occurrence of higher-level events [10, p. 227.].

As a result of the graphical representation of the fault tree, the basic events leading to the occurrence of the top event can be identified; however, their critical nature cannot yet be determined. For this purpose, they must be evaluated using the qualitative and quantitative methods previously mentioned. During the evaluation of the SMS fault tree, the qualitative method -i.e., qualitative assessment- can be applied, whereby the analysis of event cut sets allows the identification of critical basic events, so-called weak points. Weak points are those basic events within the system that fundamentally determine the occurrence of the top event and, as a result, play a key role in defining risk-reduction measures [11, pp. 48-58.].

Possible applicability of results

The formulation and analysis of the Safety Management System fault tree, as well as the identification of weak points, is not merely an analytical method but a practical tool that provides significant application benefits for operators and supervisory authorities. The methodology enables the systematic identification of risks embedded in the SMS structure, revealing their logical interconnections. As a result, the most critical areas can be designated, which can then be examined in a more targeted and prioritized manner during inspection processes. This facilitates the maintenance of the system, ensures its proper functioning, and thereby supports the continuous preservation of safe operation [12, pp. 57-65.].

For operators, understanding the weak points directly supports the improvement of safety performance. Based on the analysis, priority risk-reduction measures can be identified, which not only serve to prevent major accidents but also strengthen emergency preparedness. The results of the fault tree analysis provide a foundation for investment and maintenance decisions as well as strategic planning at the management level, as they offer an objective view of the system's vulnerabilities and development needs [13, p. 178.].

For the authorities, the application of the method also offers significant advantages. By defining a risk-based inspection focus, the efficiency of supervisory activities can be increased, and compliance assessment becomes more targeted. Information derived from fault tree analysis contributes to regulatory and methodological developments, as well as to the verification of emergency preparedness. Overall, identifying weak points not only serves to strengthen the safety culture but also to optimize operational and supervisory processes, which in the long term significantly reduces the risk of major industrial accidents [14, p. 169.].

Summary and conclusion

The Safety Management System is a fundamental component for preventing major industrial accidents, mitigating their consequences, and ensuring safe operations. It is possible, that with the Fault Tree Analysis (FTA) there can be a structured approach to identify the necessary and sufficient elements of the system, establish the logical relationships among them, and determine critical weaknesses. This analysis maybe can reveals organizational, technological, and procedural deficiencies, enabling targeted monitoring and improvement of high-risk areas. Such an approach supports risk-based inspections, enhances emergency preparedness, and fosters the continuous advancement of safety culture.

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