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Original paper

Complex Model for Risk Assessment of Industrial Processes

Katarína Holla[1]

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Abstract

This article summarises the partial results of a research project whose basic aim was to propose a Risk assessment Complex model for industrial establishments under the Seveso II Directive in the European Union. The proposed model simplifies the implementation of the Seveso Directive's obligations within the Slovak Republic. Following the development of the Complex model, the project team analysed approaches, methods and techniques for risk assessment for each phase of the Complex model. The Complex model uses a simple software tool iMotylik which contains 33 bow-tie diagrams for creating scenarios. The Project team then tested the Complex model by applying it to industrial processes in two Seveso establishments in the Slovak Republic.

Key words: Industrial accidents prevention; Complex Model for Risk Assessment; software iMotylik

1. INTRODUCTION

One of the most serious problems in the area of preventing major industrial accidents is the assessment of the risks connected with sites that process or handle hazardous substances. A risk assessment is the basis for a subsequent implementation of prevention and mitigation measures. If it is carried out incorrectly or incompletely, the risk of a major industrial accident may increase. Therefore we can say that risk assessment is one of the most important tools of risk management to prevent these crises events. (Holla et al. 2013; Salvi et al. 2008).

In the Slovak Republic we currently have a system of assessing risks of major industrial accidents according to § 6 of the Law concerning the Prevention of Major Industrial Accidents and Risk Management. It deals with the operation of the company including a corresponding safety management system and control of establishments by competent authorities at regular intervals**.** The current recommended methodology for risk assessment in Slovak Republic is actually probabilistic risk assessment (PRA) which was the most advantageous alternative, not only for the government, but also for the companies when the law became effective (2004). However, it has to be said that this methodology places greater demands on the companies in certain phases of risk assessment than is desirable by

[1] Ph.D., Department of Crisis Management, Faculty of Security Engineering, University of Žilina, 1.mája
katarina.holla@fsi.uniza.sk

Directive. Another fact is that this procedure is determined particularly for nuclear facilities.

The new Seveso III Directive transposition provides an opportunity to develop unified procedures and methodologies for use by enterprises for these types of analyses and that would potentially place lower demands on establishments in the framework of the implementation of Seveso III Directive in member states. That is why University of Žilina submitted in 2011 the project Complex Model for Risk Assessment of Industrial Processes (Complex Model) with the main goal to develop such a methodology for the Risk Assessment in Seveso establishments and this article discusses the main results of this project.

2. COMPLEX MODEL FOR RISK ASSESSMENT OF INDUSTRIAL PROCESSES

The project team of the Faculty of Security Engineering has decided to look for a solution as part of its research activities. The need to solve this problem was also based on the requirement to address this challenge from the side of the competent authorities and other stakeholders in the given issue.

The basis for building the Complex Model was to define the individual phases and steps which are the foundation for its construction. Project team analysed the legal standards which already exist in this environment, particularly the Slovak law No. 261/2002 Coll., on the Prevention of Major Industrial Accidents and Risk Management (PMIA) and other implementing Acts. In 2010 a new standard for risk management ISO 31 000 Risk Management was issued. The new approaches were implemented in the Complex Model being created. In particular, it contained some terminological changes. The new Seveso III Directive has not brought any principal changes concerning risk assessment, but is concerned mainly with adaptation to a new classification of hazardous substances, more thorough procedures for companies to inform the concerned public, and/or making the inspection processes more intensive. It leaves the member states scope for establishing their own accepted risk assessment and management approaches. Moreover, a quantitative approach to risk assessment remains an attractive option under the new Directive.

The first step in the research was to establish a simple model for assessing risks as a framework for the project – see Figure 1.

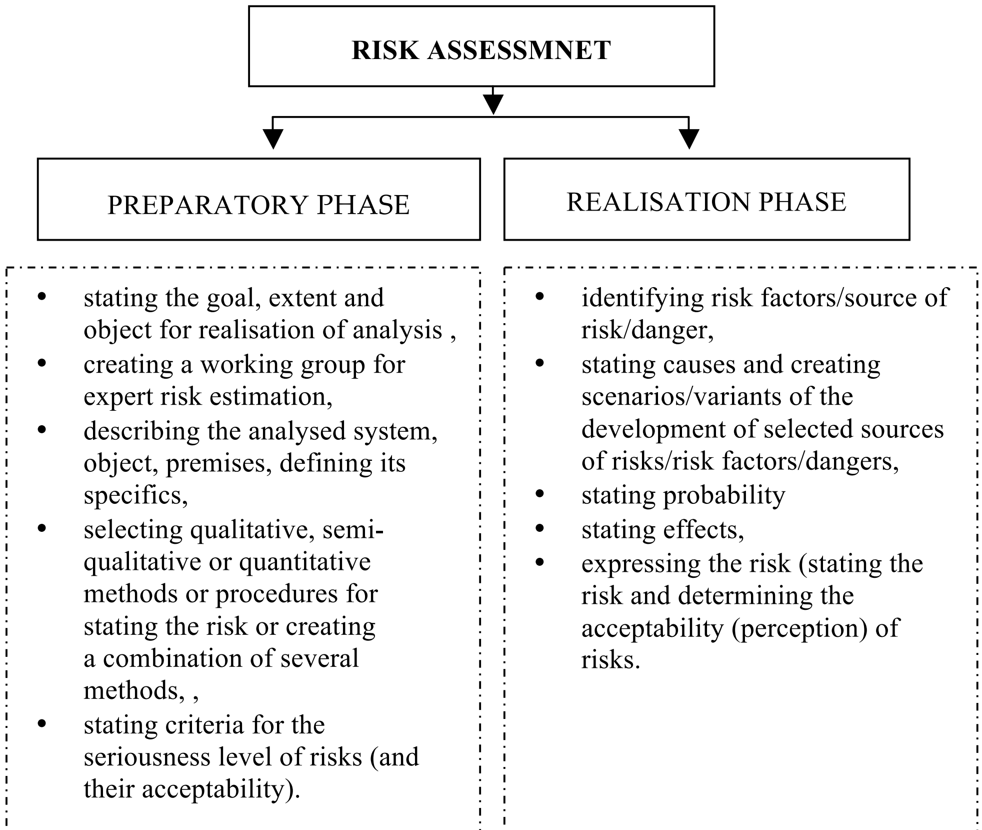

Fig. 1 Basic simplified diagram for risk assessment and treatment

From this simplified model the project team created a “Complex Model for Assessing Risks in Industrial Processes” by introducing further methodological steps.

1.1 Methodology for Developing the Complex Model

The first phase of the methodology was to determine the most important components of the Complex Model. The research study was divided into three primary activities aimed at developing the structure of the Complex Model to assess risks in establishments subject to the Seveso II Directive in the Slovak Republic:

- A needs analysis based on lessons learnt from major industrial accident prevention in the Slovak Republic and the European Union.
- An analysis and synthesis of the conclusions of a survey of Seveso establishments.
- Stakeholders’ workshops and bilateral meetings with competent authorities to analyse and assess all outputs within the project.

Need Analysis

European Union

During the first phase, information regarding risk assessment and the problem investigated was acquired particularly from foreign literature (e.g. Aven 2005; Amendola 2002) and through analysing industrial accidents (e.g. Wilson1982; Lessons learnt from accidents, 2009, 2011, 2013).

The project team also analysed global databases that gather information about industrial accidents to determine the reason for an increasing trend, and deficiencies detected by the investigations. The databases studied included:

- MARS (European) database,
- ZEMA (Germany) - the ZEMA database (Zentrale Melde- und Auswertestelle für Störfälle und Störungen in verfahrenstechnischen Anlagen) centralises information on accidents in Germany.
- ILITY (Finland) - the Finnish database ILITY gathers information on accidents worldwide (database in English).
- FACTS (the Netherlands) - is a database which contains information on more than 24,000 (industrial) accidents (incidents) involving hazardous materials or dangerous goods worldwide (restricted access).
- CCPS - the CCPS (Center for Chemical Process Safety) holds a database (restricted access) and publishes each month the *CCPS Beacon.*

A study based on a survey in 2008 made by EU-VRI (The European Virtual Institute for Integrated Risk Management) supported project team intention to suggest a solution. The objective of this study was to summarise information on the Seveso II Directive's transposition in the EU member states, information on practical experience with its weaknesses and problems connected with its implementation, the effectiveness of its implementation and the effects on European industry competitiveness. The survey evaluation brought certain conclusions and the need to revise the Seveso II Directive as well as to prepare new documents covering problematic fields. Some important survey conclusions related to the risk assessment were:

- The respondents themselves suggested the creation of new documents whose highest priority would be risk analysis and the evaluation of risks (risk assessment).
- The main problems were considered to be the lack of a unified approach to risk assessment, insufficient criteria for the risk quantification and methods to be used, insufficient tools and data for procedure implementation.
- Many enterprises carry out qualitative and not quantitative analyses and thus, the results hide a great amount of uncertainty.
- The risk assessment procedure should be harmonised with the Seveso II Directive and with the EU member state law. (Salvi et al., 2008)

Slovak Republic

In the first phase, the information regarding risk assessment was also acquired from Slovak sources (e.g. Paleček 2000; Kandráč 2012) and through analysing industrial accidents (e.g. http://charon.sazp.sk/SevesoPublic/, 2014).

A questionnaire (Hollá et. al. 2013) of 23 questions, out of which 5 were open, was further support for the project solution – it also revealed the kinds of problems encountered by companies with respect to the risk assessment. Based on this questionnaire several findings were of particular interest. The most important and relevant findings for the Complex Model were:

- An inconsistency in the approaches used and the methods of risk assessment and treatment of the industrial processes. There is no opportunity to compare results (different algorithms of the approaches based on the economic potential of the subject).
- Inadequate conditions for the application of the quantitative procedures for risk assessment.
- The lack of explanatory documents and methodologies for processing the required source data necessary for the documentation in question.
- An inconsistency in the approach to assessing risks of a natural character considering the ambiguity of data and criteria for their assessment.
- The lack of knowledge on new approaches from the point of view of the latest technical and technological developments in the field of major industrial accident prevention (Hollá K. et al., 2013).

Those problem issues which were subsequently improved in the newly built Complex Model were identified through statistical research. This survey was mainly focused on methods and techniques that should be implemented in the Complex Model.

Stakeholder´s Workshops and Dual Meetings

Another approach to achieve the objective to create and discuss the Complex Model was personal contact with selected stakeholders during workshops, dual meetings and e-mail communication. In the workshops, creation of the Complex Model and the definition of the input and output parameters were the primary issues addressed (brainstorming). The added value of these workshops was to identify perspectives on the problem solved from various points of view. The Ministry of Environment of the Slovak Republic as a competent authority considers the main problem to be the quality of the elaborated documents submitted by the Seveso establishments mainly focused on risk assessment. Processors of the safety documentation, no matter whether internal or external, do not have the required qualifications or experience, and frequently they are given incomplete materials from Seveso establishments. This also showed how important is to deal with the problem of risk assessment in this area.

2.1 Creation of the Main Structure of the Complex Model

The three basic approaches (analysis of lessons learnt, questionnaire survey and stakeholders workshops/dual meetings) contributed to the solution of the partial objective *“Setting of input and output parameters of the model on the ground of the current state analysis”* and created a primary source of information for the design of the Complex Model which forms the main output of another project objective *“Development of a Complex Model of the risk assessment of industrial processes based on new scientific approaches in the process of risk management useful in the prevention of major industrial accidents”*.

Based on the observed assumptions and analysis of the approaches currently in use, as well as newly emerging approaches, a Complex Model for the Risk Assessment of Industrial Processes was designed (Fig. 2).

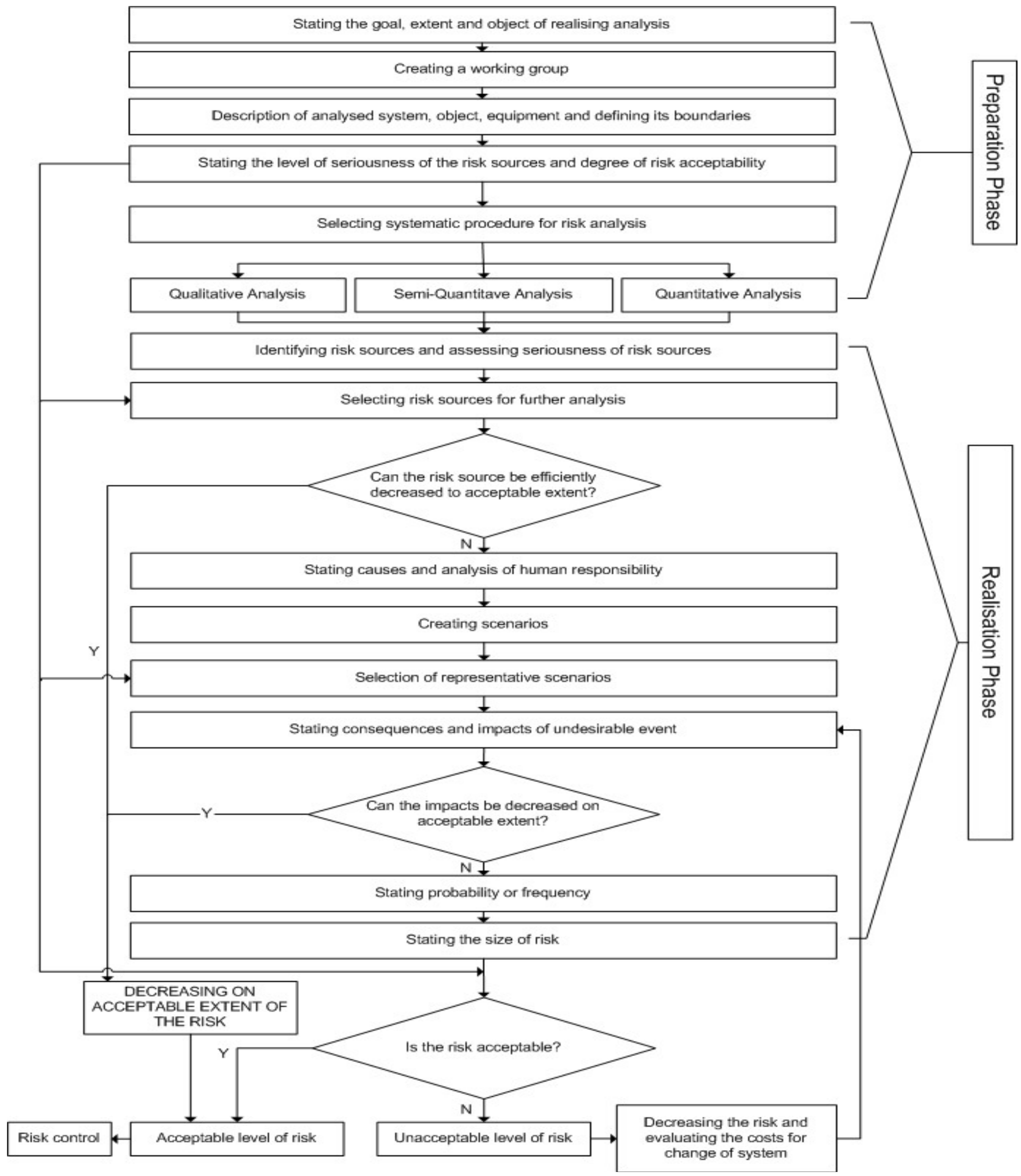

Fig.2 Complex Model for risk assessment and treatment

2.3 Methods and Techniques for the Complex Model

After creating the main structure of the Complex Model it was necessary to suggest appropriate methods and techniques for the individual steps of the different phases of the model. The project team utilised several project outputs and other tools for creating the Complex Model as follows:

- The outputs from the statistical survey performed in 2011 by the project team.
- The selected parts of the ARAMIS methodology (calculation tables).
- The tree structures for creating scenarios (developing the software iMotýlik).
- The consultations with the stakeholders concerned (Seveso establishments, risk analysts, competent authorities…).

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As already mentioned, the selection of methods for the Complex Model was also based on statistical research which was realised in 2011 and more than 60 % of companies in the Slovak Republic participated in this survey. The most frequent methods known and used by the experts were Event Tree Analysis (ETA) (39 companies, 17 %), Fault Tree Analysis (FTA) (38 companies, 16 %) and safety inspection – safety audits (26 companies, 11 %). Figure 3 depicts the most frequently used methods and techniques.

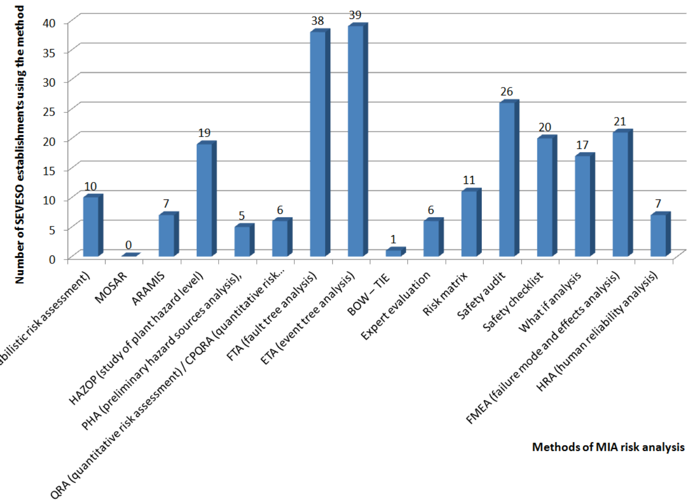

Fig. 3 The most frequently utilised methods and techniques for risk assessment and treatment (Statistical survey, 2012)

Safety inspections, check lists, Failure Modes and Effects Analysis (FMEA) and Hazard and Operability Study (HAZOP) are used especially for identifying risks. The HAZOP study for identifying the risk sources is utilised in the Slovak Republic as well as in the EU and therefore it was chosen also for this project (Zanicka Holla, K. et.al, 2010). In many cases it is possible to use other methods whose selection depends particularly on the character of the technology assessed and the hazardous substance selected.

Especially the tree techniques are used for creating scenarios in the framework of the risk assessment – the research also confirmed they are the most utilised ones in this step. These methods were utilised also in the framework of the Complex Model for creating scenarios in risk analysis step. The best alternative seems to be to create the scenarios through the bow – tie method (from the ARAMIS methodology) which combines both approaches and is graphically transparent and understandable. It offers generic fault trees and event trees which are clear, easy to use, and linked to the stated critical events. (Hourtolou, D., Salvi O., 2003) Based on this fact project team created a simple software tool iMotylik which contains 33 bow-tie diagrams for creating scenarios. The size of the trees which were created is really extensive so on the figure 4 is depicted only a cut-out of one of them as an example.

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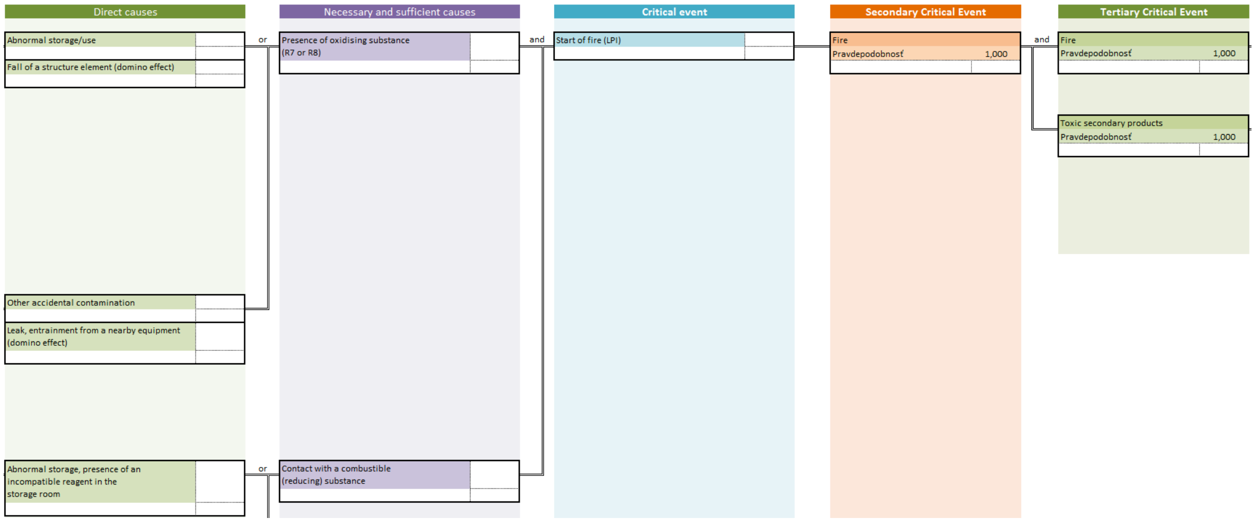

Fig. 4 Cut – out of a bow tie - start of fire (Hollá, 2014)

The combination of probability and frequency in the bow-tie diagrams create conditions for stating the resulting frequency by using Boolean algebra. The advantage of the chosen ARAMIS tables which could be implemented in the conditions of the Slovak Republic is also the possibility to select from the structured groups of barriers which subsequently increase or decrease the probability of a critical event on the side of the fault tree. The consequences of an undesirable event will be stated on the basis of created bow-ties and simulated by available software means (e.g. ALOHA) and subsequent impacts will be determined through a formula which contains all the prerequisites necessary for their expression and is introduced in the law about Prevention of Major Industrial Accidents.

The results are subsequently transferred to the Risk Matrix and compared with the acceptability level. The legal directives of the Slovak Republic state the boundary of acceptability level for the social and individual risk. It is the last step in the framework of the Complex Model for Risk Assessment. The further text brings the calculation method and the stated acceptability level.

The overall expression of impact severity is calculated according to the formula (1):

$$\mathbf{N} = \mathbf{S}.\mathbf{h}.\mathbf{f_s}, \qquad (1)$$

where:
"N" is the number of threatened persons,
"S" is the overall affected area (the 'hit' area) in [ha],
"h" is the population density of the affected area (number of persons/ha),

"f_s" is the correction factor – it is used if the affected area creates only a fraction of the hit area.

The determination of the social acceptability of the risk of a major industrial accident is realised from the point of view of a potential threat to life of one or several persons, and is defined by the acceptable probability or quantity of occurrence of major industrial accidents and is assessed by the following relation:

- If one person is threatened:
  $\mathbf{F_{pr}} = \mathbf{10^{-5}}$ for exisitng companies

$F_{pr} = 10^{-6}$ for new companies and premises

- If several persons are threatened:
  $F_{pr} = 10^{-3} . N^{-2}$ for exisitng companies and premises
  $F_{pr} = 10^{-4} . N^{-2}$ for new companies and premises (Law No. 261/2002, Coll.)

The resulting risk matrix is adapted to the conditions of acceptability which are valid in Slovakia and state the acceptability of frequency for existing and newly formed companies on the basis of the individual and social risks.

3. CONCLUSION

The prevention of major industrial accidents is one of the basic pillars for ensuring the safety of citizens both from the position of an employee or the concerned general public. The Slovak Republic as an EU member transposes the requirements of the individual directives also in this field. The currently valid Seveso II Directive will be replaced by the Seveso III Directive in 2015 and the individual member states will be forced to create new legal standards to address various changes. The period of delay between the dates of authorisation up to the deadline for transposition creates a space not only for the adaptation of all participating parties to the new conditions, but also the possibility to improve approaches especially in terminology, risk assessment , land-use planning and other problem issues. The Complex Model developed in the framework of the scientific research at the Faculty of Security Engineering can be used as a whole but also by applying selected parts in industrial processes in Slovak republic and other member states.. Its advantage lies in its use of bow-tie diagrams that link fault trees and event trees, in this way, creating a possibility to make use of generic trees for specific analyses. Also, a whole range of other methods and techniques that have not been introduced can be applied in the individual steps of this systematic procedure it depends on studied case. The main advantage of the Complex Model and software product iMotylik compared to the recommended procedure is its structural character and less demanding application. The Complex model was applied in two Seveso establishments in Slovak Republic and results of this application showed accuracy and efficiency of created approach and therefore it should be used within risk assessment of other technological processes.

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