Preventing external domino accidents: a framework for enhancing cooperation in the Chemical Process Industry (CPI)

G. Reniers¹, W. Dullaert² & K. Soudan¹
¹Department of Environment, Technology and Technology Management, Antwerp University, Belgium
²Institute of Transport and Maritime Management Antwerp, Antwerp University, Belgium

Abstract

Empirical research on major accident safety in the second largest chemical cluster worldwide, the Antwerp port area, supports the design of a meta-technical framework for optimizing external domino prevention. First, the majority of Seveso top tier companies have expressed a willingness to cooperate more intensively to protect themselves against potential off-site major accidents. Second, Hazop What-if analysis and the Risk Matrix are interesting building blocks for such a framework and are frequently used risk analysis techniques at Seveso lower tier and Seveso top tier companies. The developed framework, called Hazwim, integrates these three complementary techniques into an effective standardized risk analysis framework for the prevention of external domino accidents in an industrial area. The main strengths of Hazwim are its completeness and its cost-effectiveness. The combination of techniques on the one hand and qualitative and quantitative data on the other, offers a comprehensive up-to-date list of cross-company domino hazards and recommended actions in the area under consideration. The Hazwim framework offers support to prevention managers and safety policy makers concerning external domino prevention.

Keywords: domino accidents, knock-on accidents, escalation effects, major accidents, prevention management, cross-company prevention, chemical industry, processing industry.
1 Introduction

Large industrial areas involving plants, at which substantial amounts of dangerous substances are produced, stored or processed, hold the risk of one accident triggering a chain reaction of major incidents at adjacent plants. These chains of accidents are called ‘domino effects’. Delvosalle [1] describes a domino effect as a cascade of events in which the consequences of a previous accident are increased by following one(s), spatially as well as temporally, leading to a major accident. From the point of view of a company, domino accident risks can be internal or external in nature. Internal domino accidents originate on the enterprise premises, while external accidents are induced by neighbouring companies. Internal domino effects are usually accounted for by the design of a company safety management system, external domino effects are not.

To prevent major accidents involving neighbouring chemical facilities, the European Government has enacted the European Directive 96/82/EG of 9 December 1996 [2]. In this European Directive, a distinction is made between two types of enterprises with hazardous activities, so-called Seveso lower tier companies and Seveso top tier companies. Top tier companies endure the largest risk potential due to the greater amount of hazardous substances on the premises. Although all EU member states acknowledge that external domino effects are phenomena that can lead to catastrophic accidents in all Seveso companies, the so-called Seveso II Directive only obliges Seveso top tier companies to exchange major accident risk information with adjacent plants as article 8 of the Directive stipulates: “Member States must ensure that suitable information is exchanged in an appropriate manner to enable these establishments to take account of the nature and extent of the overall hazard of a major accident in their major accident prevention policies, safety management systems, safety reports and internal emergency plans.” The companies involved are thus obliged to exchange information with adjacent plants for the prevention of major accidents, but they are not forced to cooperate to improve off-site safety. As a result, external domino risks are not explored at cross-company level. From a social as well as from an economic point of view, preventing external major domino accidents -through improved cooperation- deserves more attention.

Recent empirical research by Reniers and Soudan [3] illustrate that safety managers acknowledge the importance of cross-company cooperation for domino risk reduction. The lack of a general framework for joint external accident prevention and the fear of high joint risk inspection and risk analysis costs, are reported to be the main objections against inter-company safety cooperation.

This paper aims at designing an economically feasible External Domino Accident Prevention (EDAP) framework that can be used for structuring cooperation between neighbouring enterprises. Taking into account empirical research on the knowledge of risk analysis tools at Seveso lower tier and top tier companies, an EDAP framework called Hazwim is proposed.
Section 2 discusses empirical data on the dispersion of the use of risk analysis procedures in the Antwerp (Belgium) port area. In Section 3, the most widespread risk identification and risk evaluation tools from the survey discussed in the previous section are forged into an external major accident prevention framework, called Hazwim. In Section 4, two adjacent chemical companies from the Antwerp port area who are currently involved in cross-company safety cooperation, evaluate the strengths and weaknesses of the proposed Hazwim framework. Section 5 concludes this paper.

2 Approach

To gain insights in the current situation on major accident risk-control cooperation in Belgian industrial Seveso surroundings and to identify the current risk analysis practice in the chemical industry subject to European Seveso legislation, semi-structured interviewing has been applied to collect data. A sample of 49 plants from a total of 311 Seveso companies in Belgium was contacted. The plants were mainly located in the port of Antwerp, the second largest chemical cluster worldwide. Out of this sample, 24 prevention managers were prepared to answer the extensive questionnaire. Out of the participating companies, 7 were labelled lower tier and 17 were labelled top tier.

![Figure 1: Cross-company cooperation in Belgian Seveso industry.](image)

Questionnaire results on current practice of cross-company cooperation are presented in Figure 1. Reniers and Soudan [3] indicate that the less risky lower tier companies are often situated in industrial areas where neighbouring companies have different core activities, entailing different risks. This is the main reason why these companies fail to cooperate, even at an information exchange level. Top tier companies with limited manpower show a restricted
interest in cooperation with neighbouring companies mainly for the same reasons as the lower tier companies. The largest top tier companies in the sample, although active members of clustering networks, prefer to work as independently as possible. However, most of the Seveso top tier companies cooperate by exchanging information with other plants in the industrial area, mainly about the quantities of hazardous chemicals present in the company. The majority of Seveso top tier companies are convinced that more intensive cross-company cooperation leads to a win-win situation possibly resulting in an effective major accident prevention strategy. About 70% of the Belgian Seveso top tier companies are willing to cooperate more intensively than only exchanging information and the same percentage realizes that major accident risk prevention cooperation will increase the company safety level.

In spite of these findings, an economically feasible major accident risk prevention framework to enhance cross-company cooperation has not been developed. For the design of such a standardized external domino accident prevention framework, the variety in risk analysis procedures and their application have to be taken into account.

Effective safety management should be based on comprehensive risk identification methods and risk evaluation and classification methods. In Figure 2, the use of risk analysis techniques in the Belgian chemical (Seveso) industry is depicted. Hazop (15%), What-if analysis (8%) and FTA (7%) are techniques that check the process safety and are therefore better suited for domino hazard identification which is often linked to process installations, pipeline networks and storage divisions of all kind. Checklists (13%) and safety audits (7%) are techniques mainly to analyze operational safety. Kinney & Fine or the Risk Matrix (13%) on the other hand can be very useful tools for evaluating and classifying risks.

Reniers and Soudan [3] point out that there are no significant differences in the dispersion of the use of risk analysis tools between lower tier and top tier plants. The fact that the same techniques are being used both in Seveso lower tier and top tier companies allows for a subset of techniques common to both types of enterprises that can be selected for the construction of an external domino accident prevention framework.

Developing an integrated risk analysis scheme which combines a well considered selection of widespread techniques would enable Seveso companies to achieve more efficient joint risk identification and could lead to joint domino safety plans in the long run. Hazop and FTA are both expensive complex techniques demanding a lot of expertise and implementation time offering very detailed safety-related documentation. A high frequency application of one of these methods is obviously not optimal. The What-if methodology on the other hand is one of the simplest forms of conducting hazard analysis. Moreover, this low-cost technique does not require special quantitative methods or extensive preplanning. A combination of some of the mentioned methods seems to be an economically optimizing alternative. In practice, the Hazop and What-if risk identification techniques have much in common, and a meta-technical complementary combination for external domino hazards assessments offers
cooperation opportunities for all the participating companies. An extended Hazop risk identification technique can be applied with well-chosen guidewords intended to verify for external domino effects hazards. The well-known risk evaluation technique of the Risk Matrix is the most applied risk ranking method in the Seveso-industry and can thus be used to evaluate Hazop results as well as What-if results.

Figure 2: Use of risk analysis procedures in Belgian Seveso companies.

3 External domino accident prevention (EDAP) framework proposal: Hazwim

3.1 Cross-company management

Cross-company management essentially differs from single company management by the amount of information managers have to their disposal. Another problem is that different organizational perspectives have to be combined. As Hovden [4] explains, each frame or perspective provides a different way of interpreting events and actions, and each implies a different focus with consequences for choice of strategies and approach to effective management.

Hence, bringing these viewpoints together is not an easy task. There should be no communication problems or misunderstandings between the parties involved. Therefore, a risk management strategy has to be worked out to be sure that responsible personnel from different plants communicate with the same know-how, on the same level, and about the same safety issues. For this purpose, a cross-company risk management overview based on a single company model from the Australian/New Zealand Standard [5] can be developed. The risk management iterative process is illustrated in Figure 3.

This overview can be used for developing a framework that supports inter-company information exchange on external domino effects. To provide a situation where communication conflicts are minimized, the risk analysis procedures and their results need to be understood by the different experts concerned with the study. In the next section, a frame is elaborated on the cross-company risk management overview of Figure 3 and based on well-known risk analysis procedures.
3.2 The Hazwim framework

The aim of an external domino accident prevention framework is to facilitate the structuring of off-site domino prevention cooperation between plants handling or storing hazardous substances. The framework should include a solid external domino risk analysis consisting of two stages providing key information for external domino risk management: external domino hazard identification and external domino risk evaluation.

Combining Hazop analysis, What-If analysis and the Risk Matrix into one Hazwim framework allows for constituting a meta-technical tool for optimizing the organization of discussing process hazard analysis performances by employees of neighbouring companies in an industrial area.

Prior to the first stage of the EDAP framework, Hazwim facilitators and experienced project managers have to be appointed in every company. In the first stage of the framework (see Figure 4), these facilitators and the project managers in each company define the scope of the external domino effects study. In the second step, an initial technical study is performed by each company to identify the potential per installation (being part of the scope area) for domino effects and their consequences. Hence, a prioritization is made and the installations are ranked in order of decreasing danger. In the next step, the company project engineer sets up the organization schedule for the scope area of the own company using the classification data and, if it is not the first time the installation is under consideration, the previously used Hazwim scheme for the installation (to decide whether an Hazop or a What-if analysis is needed). Further, Hazop and What-if teams are selected in each company. Once the teams are selected, a guided tour in the scope area of the adjacent companies is organized. The Hazwim project participants then execute stage six of the Hazwim framework. This final step of the framework cycle is completed when every installation that has been restrained to investigate for domino effects prevention in the scope area under consideration, has been checked by both parts of the Hazwim scheme.
Afterwards, together with the project managers the Hazwim facilitators define a new scope for a new area. A thorough elaboration of the different framework stages is given in subsections 3.3 to 3.8.

Figure 4: The Hazwim external domino accident prevention framework.

3.3 Step 1: Defining the scope and the scope area of an industrial area external domino safety study

Successfully implementing the domino risk analysis framework depends on efficient Hazwim facilitators’ mutual agreements. The level of detail of the Hazop and the What-if analyses to be carried out should remain within reasonable boundaries defined by the level of formal control that safety management needs to exert. The external domino safety study objective per installation such as checking the safety design of an installation, deciding where to build new installation items or to make adaptations, improving the safety of an existing facility, etc. plays a key role for establishing the area requiring focus. The scope of the study should therefore describe the types of hazards and hazard controls in the different installations to be covered by the Hazop/What-if team. For example, if the Hazwim framework is used to determine where to build a new installation having a minimal impact on public safety, it should be focused on process parameter deviations which result in off-site hazards causing danger to a public area. The physical boundaries of the EDAP framework should be made explicit to ensure that the exercise stays focused. However, being too specific can also be dangerous as it can lead to overlooking important accident sequences. At the end of this stage, concretized scope area identification can be expected, as depicted in Figure 5.
3.4 Step 2: Initial study on domino effects

Each installation in an industrial area is a potential threat to its surrounding. The whole installation area should therefore be considered in the analysis. The implementation of each Hazwim scheme is influenced by danger correlations between the installations’ process hazards on the one hand and another installation, a process unit, a collection of process units or a community on the other. Potential interactions between parts of units or facilities, which may not be hazardous in themselves but which may cause some other parts of the plant to perform abnormally and result in an accident sequence, may also exist. For example, a community may be considered as a physical boundary if transportation needs are important for hazardous material deliveries.

![Image of EDAP framework]

**Figure 5:** Identifying the scope area in the EDAP framework for two fictive neighbouring companies A and B.

In chemical enterprises where there are numerous hazards with severe potential consequences, computer programs are currently used to calculate the risk levels on a topological grid, and then to plot contours of risk on the grid. These contours are used to display the frequency of exceeding excessive levels of hazardous exposure. For example, there are software tools such as SAFETI [6], ARIPAR v3 [7], DISMA [8], Domiffect [9] and DominoXL v2.0 [10]. These computer-based programs will prepare contours for the frequency of exposure to nominated levels of heat radiation, explosion overpressure and toxic gas concentration. Risk contours are calculated by safety engineers in each company individually. Cross-company exchanging of information concerning company risk contours should result in a map as depicted in Figure 6.

3.5 Step 3: The organization schedule

The need for flexibility in applying Hazwim schemes on various installations and the involvement of different plants lead to a complex situation in which timing requirements, responsibilities and competences must be well-defined.
Each plant’s Hazwim project manager chronologically plans the various Hazwim scheme steps for the plant’s installations situated in the area under consideration. Installations in the area to be checked are listed and for every installation an overview table is made. This overview table contains at least the following estimated data: the relative danger level of each installation, the time needed to perform a Hazop or a What-if procedure on the installation and the distance to all other installations of the company. The relative danger level is calculated based on risk contours information drafted as explained in the previous subsection. It is obvious that the distance between the respective installations must be a contributing factor to the domino event occurrence potential, since the magnitude of all consequence effects reduces according to some function of the distance from the source. Based on these installation data, an optimizing time schedule to investigate external domino danger in the scope area can be drawn.

![Diagram of External domino accident prevention framework risk contours calculation for two fictive neighbouring companies A and B.](image)

Figure 6: External domino accident prevention framework risk contours calculation for two fictive neighbouring companies A and B.

An example of such a time schedule is given in Figure 7. In the example Hazop is first performed on installation A, 2 in company A. Some time later, a What-if analysis is executed on installation A, 1. In company B, a What-if analysis on B, 1 is followed by a Hazop on B, 3 and on B, 2 and finally a What-if performance on B, 4. The schedule is executed according to the Hazwim scheme from section 3.8. Information on finishing deadlines for all Hazwim performances in both companies is exchanged.

### 3.6 Step 4: Composing the Hazop and What-if teams in each company

The key to success (and efficiency) in executing a solid external domino prevention framework is the presence of appropriate skills of team members. Hazwim facilitators should be familiar with Hazop and What-if analyses as well
as with the Risk Matrix evaluation method. They should also have process and maintenance knowledge of the installations situated on the premises of their companies. Part-time members such as process engineers and maintenance engineers from the installations to be reviewed should remain on call for information assistance.

Different situations have to be considered when composing a suitable Hazop/What-if team. Per company two-risk identification procedures have to be carried out, so theoretically two teams are needed. Because the procedures are performed at different moments in time and the two teams also possess approximately the same characteristics and functions, the same team can act as a Hazop team and, reduced, as a What-if team. This way, the two types of studies are conducted mainly by the same experienced personnel. Only then the imaginative character of the What-if study will be at full strength and the least number of hazards will be overlooked. The Hazwim facilitator from a certain company is also the Hazop/What-if team leader from that company. The team should be selected as explained in section 2. The teams can be extended by specialists depending on the objectives and boundaries of the study and on the installations’ characteristics. The size of the Hazop/What-if team should be about five to nine persons depending on the study objectives and boundaries.

3.7 Step 5: Explanatory site tour

In EDAP an elementary review of the technical characters of neighbouring installations is necessary as the focus will be on hazards that can lead to off-site domino accidents. The review will allow the team members to imagine possible deviations, hypotheses and questions on the operation of the examined facility.
and adjacent facilities. Therefore, an explanatory site tour in the adjacent plant installations is indispensable. Once all team members are chosen, such a guided tour can be organized. It will support the collection of installation-specific information on risk contours and dangerous substances.

3.8 Step 6: The Hazwim process scheme

The Hazwim process scheme combines the risk identification techniques of Hazop and What-if analysis with the risk evaluation technique of the Risk Matrix. In Figure 8 is depicted how the similar and the complementary features of the three techniques can be used to integrate them into an optimal combination to decide on the actions that can be taken to stop the development of external major incidents.

![Figure 8: Hazwim process scheme.](image)

Part A of the figure consists of a risk identification performance on a chemical installation for example situated on the premises of a company A and within a certain distance to the boundary of a company B. This part of the process is an intra company technical matter. In the example, Part A is executed exclusively by personnel of company A.

The identification exercise is characterized by a bowtie structure. Central in the bowtie is the hazard; the left hand side of the bowtie describes how events and circumstances, either in isolation or in combination, can release a hazard with the potential of harm to assets, people or the environment. The right hand side represents the various scenarios that might develop from the undesired event.

In the first step of the Hazwim process, thorough risk identification determining all possible hazard causes and hazard consequences is performed using the Hazop procedure. Hazop results typically include a list of
recommendations that address the potential problems identified. Unfortunately, the results provide no guidance to decision makers as to which potential problems are most important and which are of minimal concern. Therefore, the next step in the process is a risk evaluation linked with recommended actions.

In Part B of the Hazwim process, results of Part A are discussed by safety managers of both plants to decide upon which prevention measures to take. Part B is thus a cross-company management matter.

In the next step, performed on the same installation later in time, less expensive and less time consuming risk identification is executed using the What-if analysis technique. Here also the Risk Matrix is used to classify risks and to rank the proposed protection measures. This step, using a quick creative risk identification technique, can be performed several times during a certain amount of time to determine the installations’ risk potential. The recommended frequency of What-if risk analysis performances, depicted in Figure 5 with ‘n’, varies per installation depending on installation (danger) characteristics.

After n times investigating the risks of the installation performing a What-if analysis, a more thorough risk identification by Hazop analysis is executed next to ensure optimal external domino safety.

The Hazwim process is thus a standardized but flexible scheme and time or personnel boundaries should be adapted depending on different factors and circumstances. Hazwim process implementations in a chemical industrial area are organized using the Hazwim organization schedule as explained in section 3.6.

4 Evaluation

Hazwim allows for performing a thorough cross-company external domino risk analysis, but at the expense of a certain complexity level. The scheduling of the EDAP scheme sessions can be time consuming and demanding on the company’s human resources. Highly qualified staff is indispensable and the requirements for the facilitator of the Hazwim study are high: experience in Hazop analysis, What-if analysis and the Risk Matrix. On the other hand, by judging the cost effectiveness of performing Hazop in combination with the What-if technique and by an optimization of applying the recommended actions as well as by preventing possible major accidents, the EDAP framework can be a very optimizing powerful tool to deal with external domino danger in a company.

To assess the value of the EDAP Framework, the model was discussed during brainstorming sessions with safety experts from the chemical industry. Their help is gratefully acknowledged.

5 Conclusion

Empirical research by Reniers and Soudan [3] revealed that the three constituting techniques of Hazwim - Hazop, What-if and the Risk Matrix - appear to be three of the four most commonly used techniques. The popularity of the three
techniques is crucial for Hazwim to become a solid standardized method to be widely used in the chemical industry. The proposed meta-technical Hazwim process appears to be promising in a number of respects. It combines risk analysis with risk evaluation, the two fundamentals of good safety management. Moreover, the process combines individual company policy with cross-company insights to decide upon precaution and prevention measures for curbing domino effects.

Hazop and What-if are qualitative methods with a different approach to risk identification. In Hazwim, they are integrated with the Risk Matrix technique for risk evaluation.

The structure of the Hazwim framework does not limit the creative and imaginative power of the Hazop or What-if teams. External industry evaluation suggests that the Hazwim framework, supported by the Hazwim process scheme and the Hazwim organization schedule, is a very useful instrument for company external domino safety policy decisions. It tries to offer a priority list of recommended actions to eliminate or alleviate the most dangerous off-site hazards in an effective and efficient way.

References


