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# Quantitative Risk Assessment for Industrial Units Storage of Hazardous Materials

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**Abstract—** It is necessary to appropriately integrate risk analysis with planning and transport management to prevent a potential danger being transformed into a real event. The aim of this study is to evaluate risks for workers, through a new approach that links the occupational safety health (OSH) and control of major accident Hazard (COMAH) risks, using quantitative assessment. The method has been tested at a chemical storage, in which COMAH legislation is enforced.

Workers' groups have been identified and discriminated. The individual job descriptions and the extension of the hazardous areas within the depot have been considered. In this study the values 100, 30 and 10 have been assumed to quantify the three consequence levels (lethality, irreversible, reversible effects) for a single worker. The value of every OSH risk is calculated according to values of probability and severity. In the presented case study, COMAH is relevant for 45% on the total risk. It has to be stressed that the clerks are unexpectedly, the workers' group that gives the most contribution to the total risks. The main advantage is that COMAH risks are evaluated according to criteria used in the conventional assessment applied to the occupational field. The results are useful to improve many issues of the safety management, including training, information, personal protective equipment and inspections.

**Index Terms**— Quantitative risk assessment, Hazardous materials, Occupational health, Risk probability, Risk severity, Loss prevention, Risk calculation

## 1 INTRODUCTION

The prevention of occupational accidents and diseases and the control of major accident hazards are traditionally considered two separate legislations with different approaches and methodologies.

Integration between occupational safety and health (OSH) and the control of Major Accident Hazard (COMAH) is an emerging need, due to the general trend toward an integrated management system [11].

Occupational safety is ruled by Council Directive 89/391/EEC of 12 June 1989 and daughter Directives, which have been adopted in the framework of employment and social affairs policies, aiming to protect workers. Instead, the legislation for the control of major accident hazard (COMAH) is based on Council Directive 96/82/EC ("Seveso" Directive), which has been developed in the framework of policies aiming to protect environment and citizens [1, 25]. The interest for integration is driven by many new problems, which are not manageable in a separate way. First of all, there is a general trend to unify management of OSH, COMAH, environment and security risks, as demonstrated in many papers [9]. Furthermore, even though the chemical and oil plants are the main targets of the Seveso legislation, there are many other facilities, including fireworks factory, chemical products warehouses, steel plants and foundries, are impacted.


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In these facilities the workers' density is much higher than in a typical, highly automated, chemical plant.

Even though the discussion of the quantitative methods it is not a goal of the paper, at this point it is essential to stress that these authors have considered every single job-profile and related risks. Accidental risks could be considered like interfering risks, they depend just on the spatial position within the plant and not only on the machineries, the materials and the processes used by a single worker [1, 9].

A significant attempt of sharing assessment tools was presented in a paper based on the concepts of quantitative risk analysis (QRA), usual in COMAH field. In the paper, the '"individual risk" concept, as developed in acknowledged risk analysis method [5, 21], was transferred in occupational risk assessment, in order to upgrade the set of indexes used to express occupational risks while a new index, called "individual occupational risk", was developed (1, 5). Finally, in very recent risk assessments fields the issue of quantifying occupational risk has been widely discussed [3, 11, 12].

## 2 MATERIALS AND METHODS

Risk assessment is one of the pillars of the European OSH Directives; in these Directives there are no mandatory requirements about the assessment method, which is freely selected by the duty holder; major accident risk is not explicitly mentioned in the OSH Directives [7]. For small sized facilities, including chemical depots, OSH evaluation is based on data collected in operating experience (basically injury rates) and on expert judgments or other simple methods [14]. So it is not so easy to consider a real "quantitative" assessment, but it is even possible have criteria to quantify risk level in a standardized and consistent way [13]. In this approach, the severity level of consequences must be consistent with the criteria of compensation Authority and the probability level must be compared with the typical working life cycle; in such a way the method may be considered Semi-quantitative and the evaluation may be expressed in an objective way, according to scales widely accepted [13, 21]. For the semi-quantitative approach, a risk matrix is a convenient method for ranking and presenting the final results. Also, all data, provided by the OSH risk assessment document, has been harmonized to be used in a quantitative assessment [1, 13].

## 2.1 Identification of work place

The method has been tested at a chemical depot with a few buildings for the storage of packaged chemical goods, a large forecourt for loading/unloading operations, two small plants for mixing and filling bulk products and a tall building for commercial offices. Desk activities take up most of the employees of the company at the commercial offices and just some twenty people are involved in technical activities. This structure is quite simple representative of a small sized, highly populated Seveso establishments For the purpose of the present study, workers, groups, have been discriminated on the basis of job descriptions and of the areas of depot, where they work. The paper takes into account the workers that stay in the office building (executives, managers, clerks and receptionists) and the workers in the technical area.

They are in charge of operational tasks and are equipped with the required personal protective equipment. They include forklifts operators and truck drivers, storekeepers, drum filler and chemical analysts; which work respectively at the forecourt, at the internal storage area, at the filler area and at the laboratory. The number of workers (N), including contractors, for each job profile is shown in the Table 1.

## 2.2 Risk levels

Categories of probability and severity considered in this study are shown in Table 2 and Table 3. Probabilities have been quantified by comparing the typical working life (40 years) [1, 3]. Consequences' severity has been roughly quantified, assuming for the highest damage (Lethality) the conventional value 100 and scaling consequently the lower ones. According to this schema, for each job profile, all significant occupational risks have been assessed as afterwards shown in Table 4 [1, 3, 13].

In this research, Safety Reports have been blindly trusted in, as the issue of physical modeling is not an object of the research. In the study just the top accident scenarios with probability higher than 10-6 were considered. For each scenario, typical weather conditions have been considered because they affect the direction of the damage areas involved in the event. Every job description is related to the physical space in which workers must spend most of the working time; such a data may be derived from the OSH risk assessment document. It has been assumed that the time that each worker spends out of his own working area is negligible and that the depot is open for 220 day/years from morning early to afternoon late. Even though the working times for each job profile are slightly different, they have been assumed conventionally 9am to 5pm for all workers.



Table 1. Workers' number for each job profile

| Job profile | Clerks managers | Fork lifters | Storekeepers | Fillers | Analysts |
|---|---|---|---|---|---|
| **Workers' number (N)** | 80 | 16 | 9 | 1 | 2 |

Table 2. Probability Levels [1, 3]

| Value | Level | Definition |
|---|---|---|
| 1 | Frequent | The event happens to a worker at least once a year |
| $10^{-1}$ | Probable | The event happens to a worker at least once every ten years |
| $10^{-2}$ | Occasional | The event happens to a worker not more than once during his working life |
| $10^{-4}$ | Improbable | The probability of occurrence of the event is less than 1% throughout the working life |

Table 3. Severity Categories [1, 3]

| Value | Level | Definition |
|---|---|---|
| 100 | Catastrophic | Injury or event with acute exposure to lethal or total disability Chronic exposure to lethal or completely disabling |
| 30 | Critical | Injury or acute exposure with effects of partial disability Chronic exposure with irreversible effects and/or partially disabling |
| 10 | Marginal | Injury or acute exposure with effects of reversible disability Chronic exposure with reversible disability and non-disabling |
| 3 | Negligible | Injury or acute exposure with rapidly reversible disability Chronic exposure effects with rapidly reversible disability |

### 2.3 Job descriptions and related risks

It has been considered just the main workers' tasks within a depot of hazardous goods. Occupational risks, identified for each job description, are presented in Table 4 according to the scales of probability and severity indicated in the Table 2 and Table 3.

### 2.4 Major accident scenarios

In the proposed study four top events have been considered, selected from the Safety Report [10, 11]:

***Top event n. 1:*** Loss of sulphur dioxide ($SO_2$) released from a hazardous liquid reacting with water

***Top event n. 2:*** Loss of hydrogen chloride (HCl) released from a hazardous liquid reacting with water

***Top event n. 3:*** Loss of Chloro acetyl chloride ($C_2H_2Cl_2O$)

***Top event n. 4:*** Pool fire due the loss of Tetrahydrofuran (THF) during drum operations

For each top event, the areas of depot, which workers are in and the meteorological condition for each scenarios have been considered. For each scenario, three areas have to be drawn (lethality, irreversible consequences and reversible consequences) [10, 13]. On the basis of depot's layout, areas involved in a specific top event are indicated in Table 5. The scenarios have been developed considering the meteorology-ical conditions according to Pasquill meteorological stability classes indicated as 5D and 2F [11], so seven significant scenarios have been obtained.



Table 4. Synopsis of the occupational risks for each job profile [Source: author's calculations]

| Risk | Clerks and managers | | Fork lifter | | Storekeeper | | filer | | Chemist | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P* | S* | P | S | P | S | P | S | P | S |
| Workplace | $10^{-4}$ | 10 | $10^{-1}$ | 10 | $10^{-1}$ | 10 | $10^{-1}$ | 10 | $10^{-1}$ | 10 |
| Equipment & Machineries | $10^{-2}$ | 3 | $10^{-4}$ | 10 | $10^{-2}$ | 10 | $10^{-2}$ | 10 | $10^{-2}$ | 10 |
| Electric equipment | $10^{-4}$ | 30 | $10^{-4}$ | 30 | $10^{-4}$ | 30 | $10^{-4}$ | 30 | $10^{-4}$ | 30 |
| Manual handling | - | - | $10^{-1}$ | 10 | $10^{-1}$ | 10 | $10^{-1}$ | 10 | $10^{-1}$ | 10 |
| VDUs | $10^{-2}$ | 3 | - | - | $10^{-4}$ | 3 | - | - | $10^{-4}$ | 3 |
| Microclimate | $10^{-4}$ | 3 | $10^{-4}$ | 3 | $10^{-4}$ | 3 | $10^{-4}$ | 3 | $10^{-4}$ | 3 |
| Noise | $10^{-4}$ | 3 | $10^{-4}$ | 3 | $10^{-4}$ | 3 | $10^{-4}$ | 3 | $10^{-4}$ | 3 |
| Vibrations | - | - | $10^{-2}$ | 10 | $10^{-2}$ | 10 | $10^{-2}$ | 10 | $10^{-2}$ | 10 |
| Chemical | $10^{-2}$ | 3 | $10^{-2}$ | 10 | $10^{-2}$ | 10 | $10^{-2}$ | 30 | $10^{-2}$ | 30 |
| Carcinogen & mutagenic | - | - | $10^{-2}$ | 10 | $10^{-2}$ | 10 | $10^{-2}$ | 10 | $10^{-2}$ | 10 |
| ATEX | $10^{-2}$ | 10 | $10^{-4}$ | 30 | $10^{-2}$ | 30 | $10^{-2}$ | 30 | $10^{-2}$ | 30 |
| Fire | $10^{-4}$ | 10 | $10^{-1}$ | 10 | $10^{-1}$ | 10 | $10^{-2}$ | 10 | $10^{-1}$ | 10 |
| Work-related stress | $10^{-4}$ | 3 | $10^{-4}$ | 3 | $10^{-4}$ | 3 | $10^{-4}$ | 3 | $10^{-4}$ | 3 |

*(P=Probability; S=Severity)

Table 5. The major accident scenarios and the affected depot's units

| Meteo class | Top 1 | Top 2 | Top 3 | Top 4 |
|---|---|---|---|---|
| **5D** | warehouse (G)<br>forecourt<br>filler area | warehouse (G)<br>forecourt<br>filler area | forecourt<br>warehouse (G) | filler area<br>forecourt |
| **2F** | laboratory<br>forecourt<br>warehouse (P) | laboratory<br>forecourt<br>warehouse (P) | forecourt<br>warehouse (G)<br>office building | ------ |

### 2.5 Conversion of major accident scenarios to personal risk

The number of workers in the unit (N) is another important useful parameter to evaluate the total risks [10]. In this step, the event probability has to be multiplied by the exposure rate in order to get the probability of having the individual worker involved in the accidental scenario [26]. Then The three levels of consequences, considered in major accident analysis (lethality, irreversible, reversible effects), have to be quantified, so in the study the values 100, 30 and 10 have been assumed to quantify the three consequence levels for a single worker [13, 26]. This choice is consistent with the compensation criteria of the insurance companies. In the proposed method, the equations (1, 2, 3) have been used to calculate the risk for each worker, with a specific job description, that is present in an area of depot interested by an accident scenario respectively for the three levels of consequences [26]. For each employees' group of a job profile that spend his work-time in a depot's unit, it is quantified the OSH risk and the Seveso one.

***In the equations:*** $P_{TopEv}$ is the probability associated with the top event considered; $N_{dep}$ is the presence of workers (of job profile) in the unit of depot; $A_{dep}$ is the area of unit; $A_{(L)}$, $A_{(I)}$, $A_{(R)}$ are damage areas related to, respectively, lethality, irreversible and reversible consequences for the top event considered [26].

## 3 RESULTS AND DISCUSSION

*The results of this study are shown in Table 6.* For each job profile, the mentioned table indicates the depot's unit in which they carry out their activities. The value of every OSH risk is calculated according to values of probability and severity shown in Table 4; while Seveso risk is evaluated by applying eq. 1-3 to the damage areas of the major accident scenarios. The last column indicates the relative weight of each risk. The weight of each group of workers on total collective risk is in the last row. In the presented case study, COMAH is relevant for 45% on the total risk. It has to be stressed that the clerks are, unexpectedly, the workers' group that gives the most contribution to the total risks. The use of a uniform representation of all risks is the main advantage of the proposed method; each worker's job profile is collocated in a relevant risk level on the basis of job description and space position [1]. An interesting aspect is that major accident hazards are evaluated according to criteria used in the conventional assessment for the occupational field [4]. In the proposed method, input data must be provided basically in the same format as required by the COMAH and OSH legislation [5]. This choice, even though has implied a few approximations and compromises, is essential in order to assure the application in many factories [4].

$$R_{(L)} = 100 * \sum_{TOPEV=1}^{TOPEV=N} P_{TOPEV} * \sum_{REP=1}^{rep=N} N_{dep}(A\ \ dep \cap A\,(L)_{TOPEV}) \quad (1)$$

$$R_{(I)} = 30 * \sum_{TOPEV=1}^{TOPEV=N} P_{TOPEV} * \sum_{REP=1}^{rep=N} N_{dep}(A\ \ dep \cap A\,(I)_{TOPEV}) \quad (2)$$

$$R_{(R)} = 3 * \sum_{TOPEV=1}^{TOPEV=N} P_{TOPEV} * \sum_{REP=1}^{rep=N} N_{dep}(A\ \ dep \cap A\,(R)_{TOPEV}) \quad (3)$$

Table 6. Composition of risks for all job profiles [Source: author's calculations]

| Job profile / Risk | Clerks & Managers *Office Unit* | Fork lifters *Forecourt* | Storekeepers *Warehouses* | Filers *Filling Plant* | Analysts *Laboratory* | Risk Weight % |
|---|---|---|---|---|---|---|
| Workplace | 0.0010 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 12.49% |
| Machineries | 0.0300 | 0.0010 | 0.1000 | 0.1000 | 0.1000 | 1.61% |
| Electric items | 0.0030 | 0.0030 | 0.0030 | 0.0030 | 0.0030 | 0.14% |
| Manual handling | - | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 12.45% |
| VDUs | 0.0300 | - | 0.0003 | - | 0.0003 | 1.07% |
| Microclimate | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.01% |
| Noise | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.01% |
| Vibrations | - | 0.1000 | 0.1000 | 0.1000 | 0.1000 | 1.25% |
| Chemical | 0.0300 | 0.1000 | 0.1000 | 0.3000 | 0.3000 | 2.58% |
| Carcinogenic, Mutagenic | - | 0.1000 | 0.1000 | 0.1000 | 0.1000 | 1.25% |
| ATEX | 0.1000 | 0.0030 | 0.3000 | 0.3000 | 0.3000 | 5.18% |
| Fire | 0.0010 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 12.09% |
| Work-related stress | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 |
| COMAH | 1.0563 | 1.0015 | 1.2713 | 0.0712 | 0.0434 | 49.86% |
| Group's weight % | 44.55% | 30.66% | 19.91% | 1.37% | 3.51% | 100.00% |

## 4 CONCLUSIONS

The results are useful to improve many issues of the safety management, including training, information, personal protective equipment and inspections. Furthermore, the study implicates an important economic aspect for companies; in fact, the results give the possibility to consider all risks and to evaluate their weight order to plan investments in the time. Finally, the information obtained could be exploited by insurance companies or worker compensation Authorities, where present; in fact premium reduction could be investigated to promote effective safety investments [4]. For instance, in the case study, final results suggest that the exposure of clerks to a potential accidental area contributes for about half of the overall risk's levels. A few technical interventions in this area could reduce greatly the risk's level and, consequently, insurance companies should reduce the premium.

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