A Scenario-based approach for analyzing complex cascading effects in Operational Risk Management

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ABSTRACT

This is the first paper to apply Cross Impact Analysis (CIA) and Interpretative Structural Modeling (ISM) methods for analyzing complex cascading effects in Operational Risk Management in an industrial environment. Its main objective is to improve the understanding of the overall picture of an organization's risks. The paper summarizes the development of a CIA-ISM method of the interaction of 18 critical events of an industrial plant as a first step to improving organizational resilience based on the company's own estimations as well as the estimates of a panel. The main benefit of using these methods is to know the relationships between different risks and consequences, direct links, indirect and cascading effects. Having the possibility of knowing a full risk map and being able to make a forecast will help to mitigate the unexpected effects and have a better response after an emergency situations is the same as being more resilient.

Keywords

Cross Impact Analysis, Interpretative Structural Modeling, Emergency Management, Industrial Safety and Security Management, Operational Risk Management

INTRODUCTION

For any organization to have the ability to prevent, adapt, mitigate and recover from unintended, unexpected and negative effects for the Organization (Vogus and Sutcliffe, 2007; Mileti, 2009; Labaka, 2013; Labaka, Hernantes, Laugé and Sarriegi, 2012; 2013) can mean the difference between surviving or not. In particular, for large industrial organizations with higher risk levels where the potential economic and human losses are very high (Oliver-Smith, 2002), having these skills is absolutely necessary. To have these characteristics is to be resilient and the concept is linked to the literature on the management of accidents, emergencies, business continuity and disaster recovery. Resilience is defined by Labaka (2013) as "a capacity of a system to prevent a crisis occurrence, and when a crisis occurs, the capacity to absorb the impact and recover rapidly to the normal state". This article is a study of a real case in which a risks and consequences scenario is created in an industrial plant using Cross Impact Analysis (CIA) and Interpretive Structural Modeling (ISM). At the end, the application of this methodology is highlighted as it improves the prior knowledge of the Organization in terms of its risk map, thus offering the possibility of generating predictions that help the Organization to be more resilient and to expect the unexpected.

Scenario methods should be capable to handle large amounts of information and quantitative and qualitative data. For example, a study that includes 18 events, such as the one described below, should consider $6.4023737 \cdot 10^{15}$ possible outcomes [P (n) = n!], making it almost impossible to evaluate all the different paths using the currently applied methods in Operational Risk Management. CIA-ISM method (Bañuls and Turoff, 2011) overcomes this limitation due to its computational capabilities. CIA-ISM has been successfully applied in emergency situations analysis with very good results (Bañuls, Turoff and Hiltz, 2013; Lage, Bañuls and Borges, 2013). In this paper we go a step further by applying this methodology in a new area: industrial risk analysis. This scenario methodology allows us to represent the concatenation of events that have a very low probability of occurrence but can be disastrous in the case of several occurring simultaneously in industrial contexts. The history of calamities such as the BP disaster, Bhopal, and the Chernobyl nuclear accident point to the potential value of using multiple scenarios, not to select the most likely one, but to train users in becoming familiar with a wide variety of shocks and unanticipated situations, be they hostile or not, thereby becoming superior crisis managers when confronted with a novel emergency (Bañuls, Turoff and Hiltz, 2013).

This first section describes a short literature review and methodology background followed by the Case Study where the organization, the events and all the processes to elaborate a CIA-ISM are described. Next, the Results are presented, including the Matrix and Chart for CIA-ISM and the scenarios forecasted. Finally the conclusions, limitations and future research lines are defined.

LITERATURE REVIEW

The Normal Accident Theory (NAT) (Perrow, 1984), the High Reliability Theory (HRT) (Roberts, 1990; La Porte, 1996; Van de Eede, 2009), or approaches such as Petroski (1994) and Dörner (1989) try to answer the best way to deal with situations of risk, crisis, disaster, and unwanted events. They all emphasize that the two main issues to address are the complexity of each case and evaluating the uncertainty associated directly with the concept of risk and the environment. The paradox that occurs when NAT and HRT are compared can also be seen. When the target of one organization is avoid the crisis have less focus on solve it and viceversa. Showing that they can be taken as complementary and not like antagonistic theories to expect the unexpected (another definition of resilience) (Weick and Sutcliffe, 2007a). These same authors have an extensive work about High Reliability Organizations (HRO), explaining the reasons about why they have fewer accidents than would be expected (Weick and Sutcliffe, 2007b): Preoccupation with failure, sensitivity to operations, reluctance to simplify interpretations, deference to expertise and commitment to resilience are five common HRO processes. The methodology applied in this article (CIA-ISM) is reluctant to simplify and takes data from experts' opinions.

Improved levels of resilience are almost mandatory for industrial organizations but there are problems due to the uncertainty and complexity of each case. It is therefore necessary to have a tool capable of working with risks, and complex and dynamic environments. Reviewing the literature we found that the generation of scenarios has been used to improve the capacity to respond to disasters and threats (Eriksen, 1975), prediction and estimates on earthquake disasters (Fedotov, Chernysheva and Shumilina, 1993; Barbat, 1996; Kappos, 1998), as well as resource planning and strategies (Ringland, 1998; Nguyen and Dunn, 2009) and, finally, for emergency planning (UNDHA 1993; Alexander, 2000; Bañuls, Turoff and Lopez, 2011; Aedo, Diaz, Bañuls, Canos and Hiltz, 2011; Turoff, Bañuls, Hiltz and Plotnick, 2013; 2014; Bañuls, Turoff, Hiltz, 2013; Turoff, Hiltz, Bañuls, and Van den Eede, 2013) where techniques have been applied to generate scenarios to address and predict crises, disasters, to improve the management of such situations, improve responses and to train emergency teams.

About risk analysis methodologies of industrial plant must be consider the Tixier work, a review of 62 methodologies (Tixier et al 2002) categorizing them according to the 4 properties (deterministic, probabilistic, qualitative and quantitative). The authors explain that the different methods can be categorize using the kind of input data (plans or diagrams, Process and reactions, Substances, probability and frequency, policy and management, environment, and text and historical knowledge). Next table (table XX) show some examples described in the Tixier et al paper.

	Qualitative	Quantitative
Deterministic	• Failure Mode Effect Analysis (FMEA) • Hazard and Operability (HAZOP)	• Accident Hazard Analysis (AHI) • Dow' Fire and Explosion Index (FEI)
Probabilistic	• Accident Sequences Precursor (ASP) • Delphi Technique	• Delphi Method • Event Tree Analysis (ETA)
Deterministic And Probabilistic	• Maximum Credible Accident Analysis (MCAA) • Reliability Block Diagram (RBD)	• Failure Mode Effect Criticality Analysis (FMECA) • Probabilistic Safety Analysis (PSA)

Table 1. Risk analysis categorization with examples. (Source Tixier et al. 2002)

Is highly recommendable read the Tixier et al. paper to see a complete description of this classification. In that way, HAZOP plus CIA-ISM methods used in this paper could be categorized like a Mix method that join the 4 properties and both kind of output data.

METHODOLOGICAL BACKGROUND

The methods and tools typically used in risk analysis (such as HAZOP) mostly explain direct relationships and do not explain indirect effects or cascading effects. CIA-ISM can generate scenarios, categorize the events, observe relationships and generate predictions. This is very interesting for the organization because it can work with all kinds of qualitative and quantitative data, using not only pre-existing security and prevention plans data but also being enriched by the experts' point of view, using the Delphi method or a survey of them.

In particular, Bañuls and Turoff (2011) propose a methodology that combines Cross Impact Analysis (CIA) (Gordon and Hayward, 1968) and Interpretive Structural Modeling (ISM) (Warfield, 1976) with good results in the management of emergencies. This methodology is able to identify the most important risks, the relations between them, direct effects, indirect effects and cascading effects and predict the most important elements. Other applications of this method can be found in the emergencies area (Lage et al., 2013; Bañuls et al., 2013; Turoff et al., 2013). This suggests that the use of scenarios, in particular CIA-ISM, will be a powerful tool used in industrial environments. It will identify risks and manage emergencies and disasters situations in order to improve the resilience levels of industrial organizations in which the levels of complexity, dynamism, and very high risks are the greatest threat to their survival.

The next section describes the case study carried out in this paper, the organization, the data sources and the process used to study it.

CASE STUDY

Description

This study has been performed via a theoretical and practical approach in a metallurgical plant in South Europe. This plant meets all European standards in the field of safety and prevention. This plant occupies more than 40,000m^2 and has over 250 employees. The annual production capacity is over one million tons of melting metals, more than six hundred thousand tons of refined metals and produces a surplus exceeding one million tons of acids and corrosives. The use of toxic, hazardous and polluting materials in the daily organizational activity, added to its location - a coastal area - its size and its number of workers means that the organization has a high potential risk level.

The data sources used for this work can be classified into two groups: The Organization itself and experts (both from the organization and freelancers). The Organization shared their own documentation with us and provided access to their security reports, risk assessments, risk and consequences matrix, crisis management plans, as well as a self-protection plan developed specifically for the plant. This is therefore a data source which is defined and delimited for the case study itself. These documents have been developed internally by specialists, and are put into practice under the currently applicable norm. These plans are in constant review. The initial risk evaluation start on 2009 with the help of three external consultant expert plus the participation of the own organization (around 140 participants), later in 2011 the organization extended the initial evaluation exhaustively (with the participation of 8 member of the high stuff). Moreover, a group of five professional experts in risk prevention and crisis management have actively collaborated in the case study. They have more than 10 years of proven experience in the area and are divided into two groups. The first group is made up of external consultants from the company, responsible for the supervision and review of its security plans and prevention. They also act as organizational collaborators who are highly involved with its daily work. In the second group are professionals who are independent of the organization. It has a MD specialist in crisis management, accidents and disasters, a security and prevention academician and a qualified worker with extensive experience in the sector with more than 30 actions in assistance, repair and maintenance after highly serious incidents in the same sector as the company under study. We selected five experts because it is the minimum number that can give an absolute majority consensus. It should also be noted that the total number of persons involved in total are more than 150.

To create the scenario it is necessary to delimit the events under study and the starting point was organization risk analysis. This paper uses the 11 cause events with a high Risk Value (RV = Frequency x Consequence) described in the security and safety plans and the 7 common result events for all of them. Therefore there are two kinds of events:

Cause Events: Those who are in an accident or incident causing one or more direct results, as well as possibly indirect ones to be identified. These will be classified with the letter "C", accompanied by a correlative number (C#)

Result Events: Events that have been selected not only for their RV, but also for having been identified by the Organization itself with more plausible outcomes of various cause events. These will be identified with the letter "R", accompanied by a correlative number (R #).

Events definitions

C1. Explosion and/or Fire: Event in which a fire or explosion occurs inside the plant. This may be due to a gas leak, a chemical reaction, an electrical problem, contact between molten metal and cold water, etc.
C2. Work Accident: Those accidents in which one or more persons suffer injury.
C3. Acids or Corrosives Leaks: Leakage of any element that can be included in this category, either raw or production-derived materials.
C4. SO_2 Air Pollution: the sulfur dioxide derived from the production process is very pollutant.
C5. Labor Problems: Those problems involving a work stoppage or strikes (more than 24 h).
C6. Fire Abroad: Produced by an event that occurs in the interior of the plant and that extends to adjacent places.
C7. Interruption of Supplies and/or Services: The interruption of supplies or external services that affect the production directly (for example: general energy cutoff).
C8. Raw Materials Accident: Accident on land or by sea in which involving the raw material of plant involved.
C9. External Accidents: Accidents in the facilities adjacent to the plant.
C10. Fuel Leak to the Sea: Dumping of fuel to the maritime area adjacent to the plant.
C11. Spill Toxic Solids Substances: Event occurring when catalogued solid spills occur in the facilities with toxic effects.
R1. Environmental Impact: Event whereby the environment next to the plant is directly affected by a notable incident.
R2. Accident with Severe Injuries / Deaths: Event involving serious injury for those involved, including death.
R3. Sanctions and/or Legal Penalties: Event in which the plant is seen to be economically or criminally sanctioned.
R4. Social Consequences: Negative social consequences for the plant and the organization.
R5. Operational Impact: Event by which the daily operations of the plant are affected (total or partial strike, slowdown, and so on).

R6. Customers Supplies Disruption: Case in which the customer orders temporarily or permanently cannot be served.
R7. Property Damage: Case in which the plant suffers considerable damage involving carrying out normal daily activities.

Initial probabilities

As we have mentioned previously, the Organization has documented in its array of consequences a frequency estimation for the occurrence of the cause events which is part of the analysis of its historical data, as well as the perceptions of experts who have elaborated prevention plans. In addition, this documentation provides a frequency estimate for each of the result events, given the occurrence of a cause event. These odds are the starting point for this study and their interpretation takes as a basis the previous literature on the transcription of numerical probabilities (Turoff and Bañuls, 2011) adapted for this study.

Description	**Very unlikely**	**Highly unlikely**	**Unlikely**	**Possibly not**	**Uncertain**	**Possible**	**Likely**	**Highly likely**	**Almost certain**
Probability	5%	15%	25%	40%	50%	60%	75%	85%	95%

Table 2. Probability Estimation Scale (Adapted)

After the analysis of the organizational documentation, the cause event historical occurrence matrix was obtained. This describes the estimated probability for each cause event independently.

C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**
0.25	0.25	0.25	0.75	0.75	0.05	0.05	0.05	0.05	0.05	0.05

Table 3. Historical Events Cause probability

Historical data

Table 4 shows the Cause-Consequence probability matrix that indicates the occurrence probability for all result events after cause event happens, based on the company's own records.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**
R1	0.75	0.01	0.25	0.75	0.01	0.05	0.01	0.75	0.05	0.05	0.05
R2	0.25	0.25	0.05	0.05	0.01	0.05	0.01	0.05	0.05	0.01	0.05
R3	0.25	0.25	0.25	0.05	0.25	0.05	0.01	0.05	0.01	0.05	0.05
R4	0.25	0.05	0.25	0.75	0.75	0.05	0.25	0.05	0.05	0.05	0.05
R5	0.75	0.05	0.05	0.05	0.75	0.25	0.05	0.05	0.05	0.05	0.05
R6	0.25	0.01	0.05	0.05	0.25	0.01	0.25	0.05	0.05	0.01	0.05
R7	0.75	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table 4. Event Result probability table by each Event Cause

Expert inputs

With these data it is not possible to build an impact matrix suitable for the construction of a full dynamic scenario. It is necessary to have a rating about the interrelations between cause events, as we have an assessment provided by the company between cause events and result events. As the focus of this work required more information, questions have been raised about the interrelationships of the cause events between them, since the frequency is only valued by the organization. In addition, there were questions about the probabilities of result events occurring between each other nowadays that there is this information, and given that it is logical to think that one result may cause an effect chain with another result. For example, *Property Damage* may be an *Environmental Impact* and this, in turn, pose important *Social consequences*.

To collect the necessary information the five experts was asked about the occurrence of a given cause event that is certain if another cause event has occurred. Hence, this probability was rated, according to their opinion and experience, between 5% (very unlikely) and 95% (almost certain), following the same scale discussed above. The second block of questions asked the experts about the interrelation of result events in the same way as in the first block. Both blocks of questions considered that the probability given by the expert could not be less than the initial one. This is because this has already historically happened with that frequency and to say that it is less does not make sense. But it is necessary to point out that for the second block of questions it is assumed that initially there is no relationship between the result events.

Once the experts' answers have been received, we must process them to be able to generate a CIA-ISM scenario. Therefore, we must calculate an average of all the respondents data using the Dalkey mean (Dalkey, 1971) derived from the Bayesian relationship. Following Bañuls, Turoff and Hiltz (2013) this is more appropriated than the arithmetic mean to calculate the odds of a group because it will produce a model with stronger properties of influence when there is a strong consensus in the direction of the estimates for each cell of the Cross-Impact Matrix.

Having obtained and processed this data, we will calculate the Cross-Impact Matrix. Here we assess the impact of each event per columns on the rest of the events per rows and each of these impacts will be denoted by C_{ij}. The calculation process was followed as indicated by Turoff (Turoff, 1972), where in this case the initial values are R_{ij}, the probability of a particular event happening if it has occurred before, as has been said. To calculate each of these

C_{ij} it is obviously necessary to know the values of R_{ij} and the P_i (initial odds) for each of the events. These initial probabilities have been described previously. The formula used for the calculation of C_{ij} is:

$$C_{ij} = \frac{1}{1 - P_j}\left[\varphi(R_{ij}) - \varphi(P_i)\right] \tag{1}$$

Where:

$$\varphi(P_i) = L_n\left(P_i \,/\, (1 - P_i)\right) \tag{2}$$

$$\varphi(R_{ij}) = L_n\left(R_{ij} \,/\, (1 - R_{ij})\right) \tag{3}$$

In addition to the calculation of these impacts, we can calculate the value of the Gamma (γ_i) for each of the events. That is, a measure of the effects of the events not specified by the model (external effects).

$$\gamma_i = \varphi(P_i) - \sum_{k \neq 1}^{n} C_{ik} P_k \tag{4}$$

All the results after carrying out this process are described in the following section.

RESULTS

Initial Input Matrix

As has been described before, this Initial Matrix is the result of processing all the experts' answers using the Dalkey Mean and the historical data, and it is the basis for elaborating the Cross-Impact Matrix.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**
C1	**OVP**	0.34	0.45	0.29	0.32	0.47	0.39	0.34	0.43	0.31	0.35	0.25	0.25	0.25	0.25	0.25	0.25	0.25
C2	0.68	**OVP**	0.55	0.55	0.45	0.43	0.41	0.43	0.43	0.43	0.37	0.25	0.25	0.25	0.25	0.25	0.25	0.25
C3	0.61	0.34	**OVP**	0.31	0.32	0.43	0.43	0.39	0.35	0.34	0.32	0.25	0.25	0.25	0.25	0.25	0.25	0.25
C4	0.83	0.78	0.81	**OVP**	0.83	0.81	0.85	0.80	0.81	0.77	0.79	0.75	0.75	0.75	0.75	0.75	0.75	0.75
C5	0.83	0.89	0.86	0.85	**OVP**	0.79	0.83	0.85	0.83	0.85	0.86	0.75	0.75	0.75	0.75	0.75	0.75	0.75
C6	0.24	0.13	0.27	0.11	0.11	**OVP**	0.14	0.16	0.32	0.25	0.14	0.05	0.05	0.05	0.05	0.05	0.05	0.05
C7	0.67	0.14	0.36	0.30	0.31	0.39	**OVP**	0.27	0.31	0.21	0.12	0.05	0.05	0.05	0.05	0.05	0.05	0.05
C8	0.18	0.11	0.16	0.09	0.16	0.22	0.20	**OVP**	0.23	0.13	0.09	0.05	0.05	0.05	0.05	0.05	0.05	0.05
C9	0.27	0.15	0.33	0.25	0.16	0.31	0.17	0.27	**OVP**	0.28	0.19	0.05	0.05	0.05	0.05	0.05	0.05	0.05
C10	0.19	0.11	0.37	0.14	0.16	0.22	0.27	0.38	0.30	**OVP**	0.17	0.05	0.05	0.05	0.05	0.05	0.05	0.05
C11	0.33	0.11	0.22	0.10	0.16	0.24	0.30	0.51	0.27	0.35	**OVP**	0.05	0.05	0.05	0.05	0.05	0.05	0.05
R1	0.75	0.01	0.25	0.75	0.01	0.05	0.01	0.75	0.05	0.05	0.05	**OVP**	0.25	0.17	0.11	0.29	0.06	0.39
R2	0.25	0.25	0.05	0.05	0.01	0.05	0.01	0.05	0.05	0.01	0.05	0.19	**OVP**	0.17	0.10	0.29	0.06	0.54
R3	0.25	0.25	0.25	0.05	0.25	0.05	0.01	0.05	0.01	0.05	0.05	0.86	0.78	**OVP**	0.62	0.30	0.18	0.24
R4	0.25	0.05	0.25	0.75	0.75	0.05	0.25	0.05	0.05	0.05	0.05	0.82	0.78	0.84	**OVP**	0.45	0.30	0.33
R5	0.75	0.05	0.05	0.05	0.75	0.25	0.05	0.05	0.05	0.05	0.05	0.59	0.48	0.42	0.34	**OVP**	0.78	0.73
R6	0.25	0.01	0.05	0.05	0.25	0.01	0.25	0.05	0.05	0.01	0.05	0.39	0.28	0.24	0.31	0.81	**OVP**	0.61
R7	0.75	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.36	0.24	0.22	0.22	0.15	0.05	**OVP**

Table 5. Initial Input Matrix

Cross-Impact Matrix

The following Matrix shows the impact of each event on the others after using the process that has been described before.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**
C1	OVP	0.59	1.17	0.88	1.39	1.01	0.67	0.44	0.84	0.29	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C2	2.50	OVP	1.74	5.27	3.52	0.84	0.75	0.84	0.84	0.84	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C3	2.08	0.59	OVP	1.20	1.39	0.84	0.84	0.67	0.52	0.46	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C4	0.64	0.21	0.51	OVP	1.99	0.40	0.66	0.33	0.40	0.13	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C5	0.66	1.32	1.00	2.49	OVP	0.27	0.52	0.66	0.52	0.66	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C6	2.37	1.38	2.60	3.35	3.39	OVP	1.15	1.32	2.32	1.93	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C7	4.90	1.46	3.14	8.45	8.50	2.65	OVP	2.03	2.25	1.73	1.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C8	1.86	1.11	1.72	2.68	5.08	1.75	1.66	OVP	1.80	1.09	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C9	2.60	1.60	2.97	7.39	5.08	2.25	1.41	2.03	OVP	2.11	1.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C10	1.95	1.11	3.20	4.39	5.08	1.75	2.08	2.60	2.19	OVP	1.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C11	3.00	1.11	2.25	3.00	5.08	1.88	2.22	3.15	2.06	2.43	OVP	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R1	7.59	0.00	4.66	22.77	0.00	1.74	0.00	5.99	1.74	1.74	1.74	OVP	3.51	3.05	2.53	3.76	1.86	4.18
R2	4.66	4.66	2.20	6.60	0.00	1.74	0.00	1.74	1.74	0.00	1.74	3.20	OVP	3.05	2.37	3.76	1.86	4.81
R3	4.66	4.66	4.66	6.60	13.99	1.74	0.00	1.74	0.00	1.74	1.74	6.51	5.91	OVP	5.15	3.80	3.13	3.47
R4	4.66	2.20	4.66	22.77	22.77	1.74	3.68	1.74	1.74	1.74	1.74	6.18	5.94	6.35	OVP	4.43	3.80	3.94
R5	7.59	2.20	2.20	6.60	22.77	3.68	1.74	1.74	1.74	1.74	1.74	5.03	4.55	4.34	3.96	OVP	5.94	5.67
R6	4.66	0.00	2.20	6.60	13.99	0.00	3.68	1.74	1.74	0.00	1.74	4.21	3.67	3.48	3.84	6.10	OVP	5.09
R7	7.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.05	3.47	3.34	3.36	2.86	1.74	OVP
GAMMA	-3.43	-8.99	-3.89	-0.84	-1.69	-9.98	-18.52	-10.28	-14.56	-12.11	-11.18	-25.58	-12.97	-24.16	-42.56	-30.54	-22.46	-6.68

Table 6. Cross-Impact Matrix

To read the $\boldsymbol{C_{ij}}$ components from this matrix, we must proceed in the following way: given that *C4. SO_2 Air Pollution* (Column j = 4 is true), the impact on *R1. Environmental Impact* (Row i = 12) is 22.77. In this way, we can detect, categorize and sort the greatest impacts and which of them are globally more important.

After Gamma has been calculated for all events (causes and results), it is possible to calculate the model's goodness fit. This fit is calculated by dividing the C_{ij} sum (explained impacts) by the γ_i sum (unexplained impacts), obtaining:

$$\frac{|\sum C_{ij}|}{|\sum C_{ij} + \sum \gamma_i|} = \frac{659.3086}{919.71639} = 0.7168 \approx 71.68\% \qquad (5)$$

The model presents a fairly high explanatory capacity, even assuming that there are significant external impacts in the case of result events, as was indicated in the γ_i. This means that at this time we have very high expectations about the model's predictive capacity.

Scenario Modeling

Once the impact matrix has been obtained, the next step is the implementation of ISM for the generation of a risk map. Here is an analysis of the distribution of the C_{ij} values that will help to select the most suitable cutting for the scenario creation.

Percentile	C_{ij}		**Percentile**	C_{ij}
95%	7.5214		**50%**	2.1503
75%	3.9479		**25%**	1.3863

Table 7. Percentile Value Table.

Taking the $P_{(50)}$ with an C_{ij} > 2.1503 as a reference has generated a CIA-ISM map of risks using the method described by Warfield in 1976, with the difference that the graphic representation has been done from top to bottom. The elaboration of this stage is done with C_{ij} values > 2.1053, counting a total of 104 severe impacts: 33.98% of the total number of possible impacts.

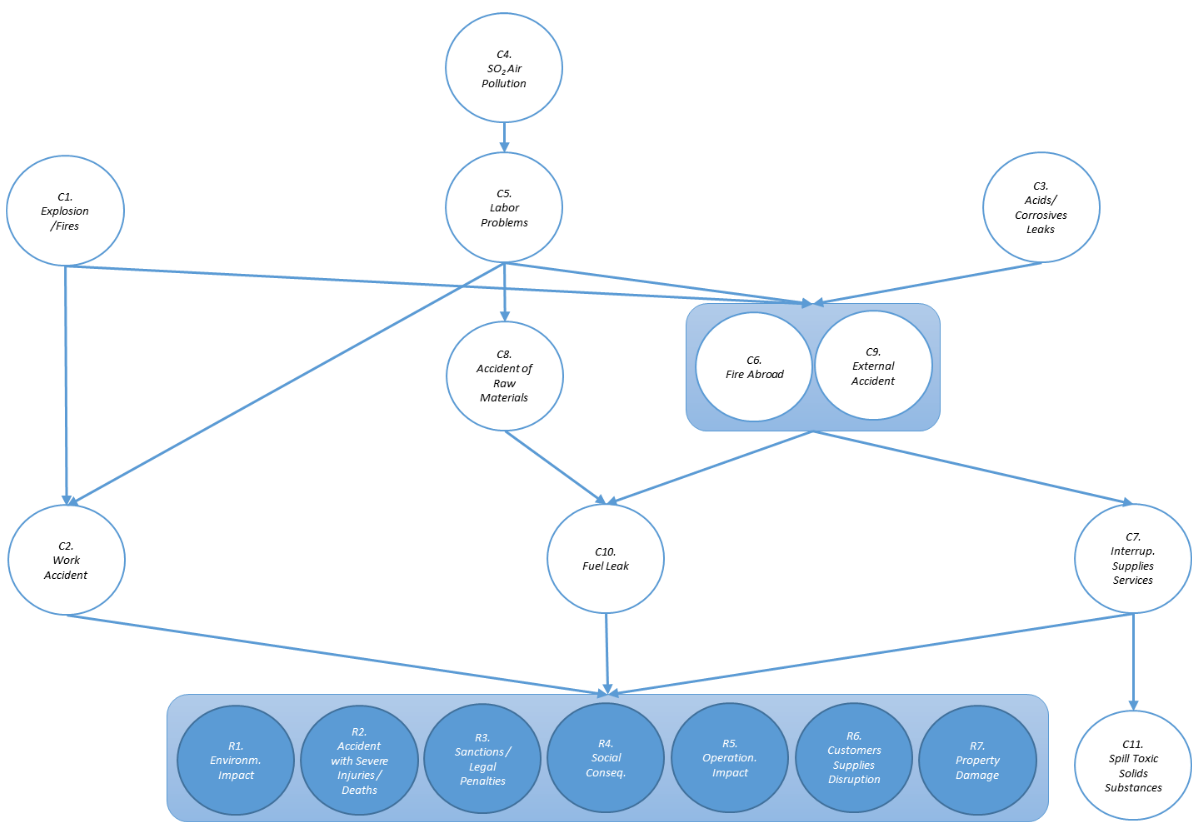

Figure 1. C_{ij} >2.1503 Digraph

This figure shows the relationships between all kinds of events. The white circles correspond to Cause Events and dark ones to Result Events. The rectangles show events in a micro-scenario. A micro-scenario is a particular situation where all events have a reciprocal relationship. This figure is a risk map and shows all events in 5 horizontal levels (the highest are event triggers) and presents two micro-scenarios, stressing that all result events are a single micro-scenario. All results have relationships between each other and almost all events cause direct or indirect impacts on them, with the exception of C11. The first "micro-scenario cause" (C6, C9) is also created. A fire with effects abroad (C6) is mutually linked to an external accident (C9) and vice versa. It is also observed that C1 (fire/explosions), C3 (leakage of acid), and C4 (SO_2 pollution) are trigger events.

Scenario Simulation

Once this first scenario is created as a starting point, it is possible to recreate a simulation using a predictions system developed by Turoff (1972) where the entire CIA method calculation process is explained. To indicate this, the following paragraph shows the formula that was used to calculate the predictions.

$$P_i = \frac{1}{1 + \exp(-\gamma_i - \sum C_{ik} \cdot P_{ik})} \quad (6)$$

To generate a prediction for all combinations of occurrence or non-occurrence for all the elements would be too large; therefore this paper shows an example based on the previous map. The initial probability (P_i) of the events has been modified to force its occurrence or non-occurrence in different combinations. In particular, these predictions have been developed by modifying the values of C1 (fire/explosion) and C2 (work accident). As well as the chain of related events, C1→C2→ [R1, R2, R3, R4, R5, R6] builds 3 simulated scenarios. The next chart shows the modified Cause Events (C1, C2) using a grey color.

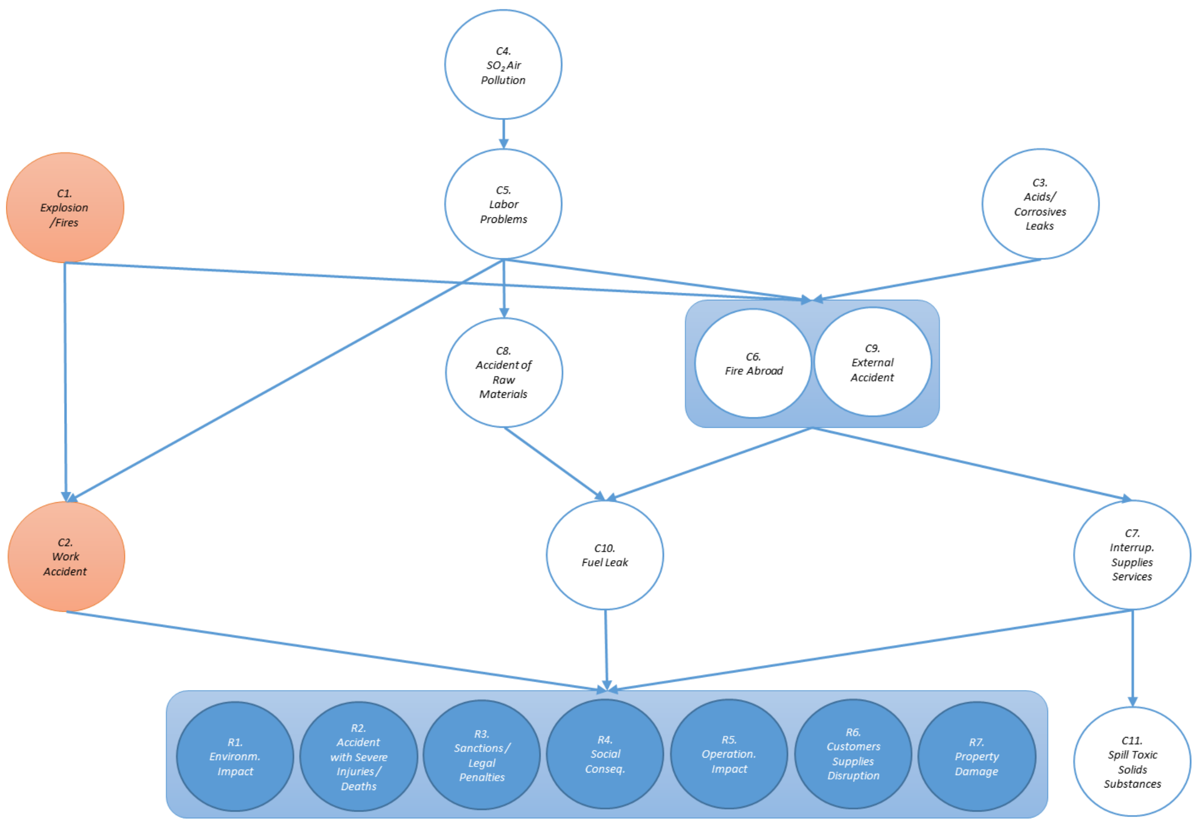

Figure 2. C_{ij} >2.1503 Digraph (Events Cause marked to forecast)

The following table shows the case occurrence for each scenario being 1 if the event occurs, 0 if it surely does not occur and "?" if it is uncertain. In all scenarios "R =?" because we want to know the final effects on the Result Event and the most probable results in each scenario.

	C1	C2	R's
Scenario C	?	?	?
Scenario I	1	1	?
Scenario II	1	?	?
Scenario III	1	0	?

Table 8. Event Cause per Scenario.

- Scenario C would correspond to the Original model. It serves as a comparison.
- Stage I to an Explosion/Fire with personal accident.
- Stage II to an Explosion/Fire without knowing the consequences.

- Stage III to an Explosion where it is sure that there is NO Personal Accident.

The simulations offer the following results once different combinations of data have been introduced.

Scenario I:

In this scenario, the probability of Sanctions and Legal Penalties (R3) and Operational Impact (R5) is more than 90% (near to almost certain). In addition, the occurrence of Environmental Impact (R1) and Property Damage (R7) would be close to Likely (75%). Chain effects with other Cause Events can also obviously be detected: SO_2 Air Pollution (C4), Labor Problems (C5) and Supplies/Services Interruption are more than probable secondary effects in this scenario.

Scenario II:

If an Explosion/fire happened, this would probably involve an Environmental Impact (R1), Operations Impact (R5) and Property Damage (R7). As in the previous scenario effects are also observed in other events. Air pollution by SO_2 and Work Problems continue having a high value, while Supplies and/or Services Interruption are now possible because the probability has decreased. Work Accident will still be present.

Scenario C		Scenario I		Scenario II		Scenario III	
C1	**25.00%**	**C1**	**100.00%**	**C1**	**100.00%**	**C1**	**100.00%**
C2	**25.00%**	**C2**	**100.00%**	**C2**	**68.46%**	**C2**	**0.00%**
C3	25.00%	C3	71.15%	C3	61.37%	C3	57.85%
C4	75.00%	C4	85.00%	C4	82.86%	C4	82.09%
C5	75.00%	C5	93.01%	C5	83.13%	C5	77.97%
C6	5.00%	C6	46.72%	C6	23.69%	C6	18.01%
C7	5.00%	C7	86.11%	C7	67.43%	C7	58.95%
C8	5.00%	C8	32.83%	C8	17.55%	C8	13.90%
C9	5.00%	C9	55.01%	C9	26.96%	C9	19.85%
C10	5.00%	C10	34.35%	C10	18.56%	C10	14.73%
C11	5.00%	C11	53.45%	C11	33.35%	C11	27.50%
R1	**1.00%**	**R1**	**75.00%**	**R1**	**75.00%**	**R1**	**75.00%**
R2	**1.00%**	**R2**	**91.67%**	**R2**	**25.00%**	**R2**	**9.41%**
R3	**1.00%**	**R3**	**91.67%**	**R3**	**25.00%**	**R3**	**9.41%**
R4	**1.00%**	**R4**	**63.46%**	**R4**	**25.00%**	**R4**	**16.13%**
R5	**1.00%**	**R5**	**93.99%**	**R5**	**75.00%**	**R5**	**63.38%**
R6	**1.00%**	**R6**	**25.00%**	**R6**	**25.00%**	**R6**	**25.00%**
R7	**1.00%**	**R7**	**75.00%**	**R7**	**75.00%**	**R7**	**75.00%**

Table 9. Forecasted Probabilities per Scenario.

Scenario III:

The occurrence of an Explosion/fire with **NO** Work Accident (C2) would probably lead to an Environmental Impact (R1) and Property Damage (R7), and possibly some kind of Operation Impact is still present. The table also shows that SO_2 Air Pollution (C4) and Work Problems continue being probable. On the other hand, the Supplies and/or Services Interruption (C7) is now uncertain.

Initial Expert Validation

The analysis of the CIA-ISM results of Predicted Scenarios was communicated to the experts who participated in the initial data prospection and they must fill out a satisfaction questionnaire about the results reported. The experts had to rate the question on a 7-point Likert scale (from "1=Total Disagreement" to "7=Total Agreement"). The following table shows the questions asked and the arithmetic mean of the values of the responses.

Question	Answer (Mean)
The CIA-ISM method is a suitable tool to generate Risk Maps.	7
The Risk Scenario properly identifies the risk including the importance, direct, indirect and cascade effects.	7
The Risk Map shows logic relationships which agree with my own opinion.	6.8
The Scenarios Forecasted show logical results which agree with my own opinion.	6.6
The Risk Map and Scenarios Forecasted could be used to enhance the resilience level	6.8

Table 10. Expert satisfaction responses.

All answers were marked with a value higher than "Mostly Agree" and the last one, which asks about how the risk maps can be used to increase the organizational resilience level was marked with 7 - “Total Agreement” - showing that all the experts were fully agreed. All the experts interviewed agreed that this CIA-ISM method is valid to be applied for the improvement of organizational resilience and most agree with the use of this method to elaborate organizational risk maps.

CONCLUSIONS, LIMITATIONS AND FUTURE RESEARCH

This paper has been the first development of an industrial risk map based on CIA-ISM, categorizing risks by importance, showing the cascading effects and identifying the micro-scenarios generated. We have illustrated how the CIA-ISM method help us to understand the big picture of Operational Risk Management in a complex organization with less information loss and in line with the opinions of experts. This helps to show non-obvious relationships and in addition allows the creating of forecasts that would allow the organization to improve its safety and prevention plans. In other words, it helps the organization to be ready to deal with unexpected emergency situations, improves the preparation of the emergency teams and helps to develop better mitigation plans and be more able to have a fast recovery and being more resilient.

This analytical and graphical industrial risks events study improves the understanding of organizational risk. This is done setting out from a prior basic knowledge (risk matrix) and working with experts. This method helps organizations to deal with the five processes described by Weick and Sutcliffe (2007). As main result, this work can improve the Organizational State of the Art from being a one-dimensional and static risk analysis to one that is multidimensional and dynamical, using all kinds of data (qualitative and quantitative), not using simplifications and deferring to experts.

At this point we must refer once again the Tixier et al paper. In the conclusions Tixier propose the main characteristic of a good risk analysis methodology. The method must identify four parts in an exhaustive way and together with their interactions. “*Then should permit a deterministic and probabilistic approach with a hierarchisation phase and finally, the output data could be of two different types*”.

Parts	Output Data
The source (Industrial establishment) The flux (Vector of propagation) Targets (Human, enviromental and equipments) Control and management	Qualitatitive in order o provide recomendations Quantitative in order to evaluate the main consequences

Table 11. Parts and Output data (Tixier et al. 2002 conclusions)

Finally Tixier wrote that with this elements the methodology will provide some ways of improvement and help in decision making. In this paper we combine the previous knowledge of the own organization (HAZOP) plus CIA-ISM. The result is a combination of methodologies that complete all parts: Source, targets and control may explained by HAZOP and Flux by CIA-ISM. And about Output data Qualitative is provide by HAZOP and Quantitative by CIA-ISM. So we propose a more complete and powerful method to help us in two ways: Risk analysis and decision making.

By means of an initial validation with an expert panel, we can say that dynamic scenarios implementation through CIA-ISM in the operational risk field is at the very least promising. The model obtained by using this scenario generation method suggests the adequacy of this methodology for risk modeling and resilience analysis in industrial organization. The expert panel answers show that the scenarios and predictions presented have been well rated, with a score higher than 6 on a 7-point Likert scale.

This research has some limitations. The size of the expert panel is reduced, being the minimum required by literature, and only one round of questions was carried out. A multi-round Delphi process would add more valuable information. Notwithstanding, from our perspective this limitations have not a critical impact on the validity of the results due the composition of the panel and the coherency of the outcomes obtained through the simulation. We propose as future research lines: an expansion of the study to other similar companies to validate the model in other context: characterizing result events according to resilience type; calculating the probabilities of the micro-scenarios; practical simulations with a group of experts to validate the predictions and to verify that these are interesting for the risk plan development that will improve organizational resilience; validating the results of the model predictions using forensic analysis or other tools. We are now focused on extend this research beyond one single-time prediction as part of a dynamic forecasting method to discover non-obvious results and provide more information to the organization to help it at decision making process.

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