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A CIA–ISM scenario approach for analyzing complex cascading effects in Operational Risk Management

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ABSTRACT

This is the first paper to apply a combination of HAZOP and Risk Consequence Matrix plus Cross Impact Analysis (CIA) and Interpretative Structural Modeling (ISM) methods for analyzing complex cascading effects in Operational Risk Management in an industrial environment. This combination of methods allow obtain more information than using HAZOP and Risk Consequence Matrix because upgrades the individual risk analysis with the correlation between risks. Its main objective is to improve the understanding of the overall picture of an organization's risks. The paper summarizes the development of the combination of this methods 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 an expert 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/unprepared effects and have a better response making better decisions after an emergency situations is the same as being more resilient.

1. 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, 1999; Labaka, 2013; Labaka et al., 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 this concept is linked to the literature on the management of accidents, emergencies, business continuity and disaster recovery. This article is a study of a real case in which a risks and consequences scenario is created in an industrial plant using previous risk analysis documentation (Hazop and Risk Consequence Matrix) plus Cross Impact Analysis (CIA) and Interpretive Structural Modeling (ISM) (Fig. 1). 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 of handling 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 1.7403456e+16 possible outcomes [$P(n)=e*N!$] (Turoff, 1972), making it almost impossible to evaluate all the different paths using the currently applied methods in Operational Risk Management. The 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 and has had very good results (Bañuls et al., 2013; Lage et al., 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

Abbreviations: AHI, Accident Hazard Analysis; ASP, Accident Sequences Precursor; CIA, cross-impact analysis; CIASS, web-based tool for simulation and forecasting. www.ciass.org; ETA, Event Tree Analysis; FEI, Dow Fire and Explosion Index; FMEA, Failure Mode Effect Analysis; FMECA, Failure Mode Effect Criticality Analysis; HAZOP, Hazard and Operability; HRO, High Reliability Organization; HRT, High Reliability Theory; ISM, Interpretative Structural Modeling; MCAA, Maximum Credible Accident Analysis; NAT, Natural Accident Theory; PSA, Probabilistic Safety Analysis; RBD, Reliability Block Diagram

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and unanticipated situations, be they hostile or not, thereby becoming superior crisis managers when confronted with a novel emergency (Bañuls et al., 2013).

This first section describes a short literature review and methodology background following 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. At the end, we explain how the CIA–ISM method could be used as a part of a decision support system, helping us to deal with non-obvious results. Finally the conclusions, limitations and future research lines are defined.

2. Literature review

The Normal Accident Theory (NAT) (Perrow, 1984), the High Reliability Theory (HRT) (Roberts, 1990; La Porte, 1996; Van den Eede, 2009), or approaches such as Petroski's (1994) and Dörner's (1989) try to show 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, showing that they can be taken as complementary and not 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 adverse to simplification, takes data from experts' opinions, and can be a great tool to increase the organizational resilience level if the organization wants to deal with risk and crisis situations and minimize their occurrence.

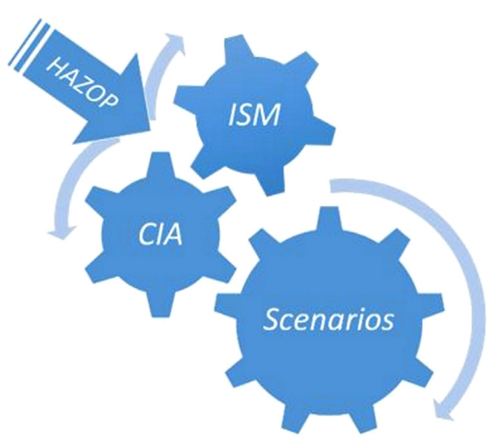

Fig. 1. Methodology process.

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 et al., 1993; Barbat, 1996; Kappos et al., 1998), as well as resource planning and strategies (Ringland, 1998; Nguyen and Dunn, 2009) and, finally, for emergency planning (UNDHA, 1993; Alexander, 2000; Bañuls et al., 2010, 2013; Aedo et al., 2011; Turoff et al., 2013a, 2013b, 2014) where techniques have been applied to generate scenarios to address and predict crises, disasters, to ameliorate the management of such situations, to better responses and to train emergency teams.

Tixier et al.'s work about risk analysis methodologies of industrial plant must be considered. This is a review of 62 methodologies (Tixier et al., 2002), categorizing them according to 4 properties (deterministic, probabilistic, qualitative and quantitative). The authors explain that the different methods can be categorized 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). It also should be noted that most of the methods concerning risk analysis only consider each risk individually. Table 1 shows some examples described in the Tixier et al.'s paper.

Reading Tixier et al.'s paper is highly recommendable to see a complete description of this classification. In this way, HAZOP and the Risk Consequence Matrix plus the CIA–ISM methods used in this paper could be categorized as a Mix method that joins together the 4 properties and both kinds of output data. 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 the next section we introduce the fundamentals of this methodology.

3. CIA–ISM fundamentals

CIA–ISM (Bañuls and Turoff, 2011) combines Cross Impact Analysis (CIA) and Interpretive Structural Modeling (ISM) with good results in the management of emergencies, being 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

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

	Qualitative	Quantitative
Deterministic	• Failure 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)

be found in the emergencies area (Lage et al., 2013; Turoff et al., 2013a, 2013b; Bañuls et al., 2012, 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 disaster situations in order to improve the resilience levels of industrial organizations in which the degrees of complexity, dynamism and very high risks are the greatest threat to their survival. In this section we discuss the main steps of this methodology.

3.1. Cross Impact Analysis

In this research we used the Turoff approach to Cross Impact Analysis (Turoff, 1972). Cross-impact analysis is considered as an attempt to obtain estimates of the correlation coefficients between events. The basic difference between Gordon and Turoff is that the Gordon asks about correlations directly while Turnoff's approximation asks about subjective probabilities between events and then calculates the correlations.

3.1.1. The event's characteristics

The events to be analyzed must have two properties.

- They are expected to happen only once in the interval of time under consideration (i.e., non-recurrent events).
- They do not have to happen at all (i.e., transient events).

Working with non-recurring events in turn implies accepting the concept of subjective probability.

3.1.2. Possible paths (number of scenarios)

One advantage of using CIA in a complex environment with many events is that we can reduce the demand for information needed for the analysis of a complete scenario. If we follow the same example that Turoff indicates, in a model where we manage N elements that cannot be repeated (they only happen once and their status cannot be changed again) the number of possible paths (scenarios) is equal to $N{*}2^{N-1}$. An example with 3 events can be examined under these lines; this example provides 12 possible paths (1 is an event which happens, 0 an event which does not happen) (Fig. 2).

With 18 possible events the number of possible paths grows considerably ($N=18$, $N{*}2^{N-1}=18{*}2^{17}=2{,}359{,}296$). This is because it is assumed that work with a "no memory system" where an event has once occurred cannot happen, therefore the probability of a transition from one state to another is not dependent on the route used. If we assume that the system is a "memory system", the number of transition probabilities to specify the problem completely would be $eN!$ ($N=18$; $e{*}18!=1.7403456e+16$).

One of the advantages of using CIA implies that the number of questions to ask the experts is only N^2 (in a model of 18 elements this would be a maximum of 324). Turoff compares all 3 cases using Table 2.

All the mathematical explanations are described in Turoff (1972). The calculation of the correlation coefficients (or impacts, C_{ij}) can be calculated using a variation of the Fermi–Dirac distribution function, using the previous calculated data (Initial

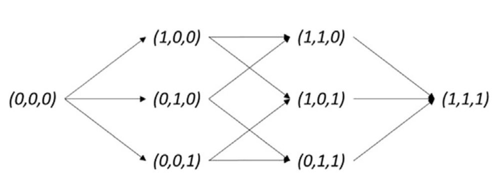

Fig. 2. Transitions and states for 3 events.
Source: Turoff (1972)

Table 2
Data demands comparative.

Number of events N	Cross impact N^2	No memory system $N{*}2^{N-1}$	Memory system $\approx eN!$
2	4	4	5
3	9	12	16
4	16	32	65
5	25	80	326
10	100	5120	9,864,101
18	324	2,359,296	17,403,456,103,284,400

Probabilities and Dalkey Mean probabilities as this relationship determines).

$$P_i = 1 \Big/ \left[1 + \exp\left(-G_i - \sum_{i \neq k} C_{ik} P_k \right) \right] \tag{1}$$

We therefore consider that using CIA employing the method described by Turoff confers an advantage over other methods, such as the use of Bayesian calculations, since it requires a smaller amount of information and as the Bayesian approach to modeling this subjective probability process does not appear to fit or explain the judgments made. This is why we think that the use of subjective probabilities employed in this approximation is closely related to the subjective nature of the experts' opinions and the use of the Turoff approach. This method would allow the inference of the probability of occurrence of events with no statistically-significant history of occurrence (as with most risks and accidents in an industrial environment).

This approach was used to analyze complex scenarios in another kind of environment with great results. Also we do not need to know prior to the study how the relationship structure between events is before the analysis, as we do with the Bayesian tree analysis. This reduces the amount of information needed to elaborate a complete scenario and calculate all possible paths. With all the correlations calculated, we will know all the relationships between the events described that we need to elaborate scenarios and forecasts.

3.2. Interpretative Structural Modeling (ISM)

As with the CIA method described above, there is a good deal of literature about the ISM method (Warfield, 1976). In this section we will describe the process that we used to elaborate the digraphs following the same process that is described by Bañuls and Turoff (2011).

Once we have the Impact Matrix, we must convert it into a positive and binary matrix as is required by ISM. To do this we need to take an arbitrary value. This value could be calculated using a Percentile analysis of all impact matrix records. After obtaining this value, we can follow the mathematical process described by Bañuls and Turoff and transform our impact matrix into a binary matrix. The binary matrix is a representation of occurrence or no-occurrence of all the events described. This is the main data source to apply the ISM.

ISM will show us which of the events have occurred and the relationship between them. The digraphs show us which events are triggers and indicate the results sorted by levels – the original method exhibits the triggers in the bottom place, and we consider that is better to place them at the top, as we describe in the following sections. The ISM show how some events happened together, creating a kind of mini-scenario or macro-event. This means that all the events inside are closely and reciprocally related.

So, with all this information we have all the correlations between events (at least all those between which we want to know the relationship) and a graphical representation of the scenario (for the arbitrary value chosen). The digraphs graphically show some easy to understand information and present us with the graphical relationship structure of the scenario. This structure is unknown before the calculations because we did not know the correlations. Therefore it was impossible to apply the Bayesian tree analysis before.

3.3. Simulation and forecasting method – CIASS

With the Impact Matrix we can elaborate some simulations and predictions using the CIA method. Once we know the initial probabilities and have calculated the correlations between events we can use them to make simulations and forecast some scenarios.

The process is really easy to understand. We can force the initial probability of one or more event (0 if we do not want this event to happen, 1 if we force it to happen). After that, we can make all the calculations to know what happened with the scenario and compare the results. In this research we did all the calculations using a spreadsheet and then compared the results with CIASS.

CIASS is a web-based tool which lets us load the main data (impact matrix) and all the event descriptions. Once the data is uploaded, the researcher or practitioner can "play" with the probabilities to create simulations. These results can be compared between each other. The tool only shows the probabilities and colors, but the developer's team is working to add some functionalities, as the digraphs also show.

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

4. Case study

4.1. 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. It occupies more than 40,000 m^2 and has over 250 employees. The annual production capacity is over one million tons of molten metals and 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 (Hazop and risk analysis documentation) 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 and 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 started in 2009 with the help of three external consultant experts plus the participation of the organization itself (around 140 participants). Later, in 2011, the Organization extended the initial evaluation exhaustively (with the participation of 8 members of the top staff). 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. There is an MD specialist in crisis management, accidents and disasters, a security and prevention academician and a qualified worker with extensive experience in the sector who has carried out 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 this is the minimum number that can give an absolute majority consensus. It should also be noted that the total number of persons involved is 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 × 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 which 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 as having more plausible outcomes of various cause events. These will be identified with the letter "R", accompanied by a correlative number (R#).

4.2. 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 metals 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 which 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 involving the raw material of plant.

C9. External Accidents: Accidents in the facilities adjacent to the plant.

C10. Fuel Leak to the Estuary: Dumping of fuel to the maritime area adjacent to the plant.

C11. Toxic Solid Substances Spill: Event occurring when cataloged solid spills occur in the facilities with toxic effects.

R1. Environmental Impact: Event whereby the environment close 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.

4.3. 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 (Hazop and Consequence Matrix), 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 (Bañuls and Turoff, 2011) adapted for this study (Table 3).

After the analysis of the organizational documentation, the cause event historical occurrence matrix (Table 4) was obtained. This describes the estimated probability for each cause event independently.

4.3.1. Historical data

Table 5 shows the Cause–Consequence probability matrix that indicates the occurrence probability for all result events after a cause event happens, based on the company's own records.

This table only shows the odds between Events Cause and Events Results and does not show any information about the relationship between Events Cause or the relationship between Events Results. To have a complete vision of correlations we must ask the experts about their subjective opinion of these relationships to be able to calculate all the correlations needed for this working model.

4.3.2. 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. Given that the focus of this work required more information, questions have been raised about the interrelationships of the cause events, since the frequency is only valued by the Organization. In addition, there were questions about the probabilities of result events occurring between each other now that there is this information, and granted 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, every expert 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, 1972) derived from the Bayesian relationship. Following Bañuls et al. (2013) this is more appropriate 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 column on the rest of the events per row and each of these impacts will be denoted by C_{ij}. The calculation process was followed as indicated by 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 (the initial odds) for each of the events. These initial probabilities have been described previously. The formula used for the calculation of C_{ij} was obtained from previous formula (1):

$$C_{ij} = \frac{1}{1-P_j}\left[\varphi(R_{ij}) - \varphi(P_i)\right] \quad (2)$$

where

$$\varphi(P_i) = L_n\left(P/(1-P_i)_i\right) \quad (3)$$

$$\varphi(R_{ij}) = L_n\left(R_{ij}/\left(1-R_{ij}\right)\right) \quad (4)$$

In addition to the calculation of these impacts, we can calculate the value of the Gamma (γ_i) for each of the events. Gamma is a

Table 4
Historical events cause probability.

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 5
Event result probability table by each event cause.

	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 3
Probability estimation scale (adapted).

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

measure of the effects of the events not specified by the model (external effects).

$$\gamma_i = \varphi(P_i) - \sum_{k \neq 1}^{n} C_{ik} P_k \tag{5}$$

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

5. Results

5.1. Initial Input Matrix

As has been described before, this Initial Matrix (Table 6) 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.

5.2. Cross-Impact Matrix

The matrix in Table 7 shows the impact of each event on the others after using the process that has been described before.

To read the C_{ij} components from this matrix, we must proceed in the following way: given that *C*4. *SO_2 Air Pollution* (Column $j=4$ is true), the impact on *R*1. *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

$$\frac{\sum |C_{ij}|}{\sum |C_{ij}| + \sum |\gamma_i|} = \frac{659.3086}{919.71639} = 0.7168 \approx 71.68\% \tag{6}$$

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.

6. 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

Table 6
Initial input 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	0.8	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	0.3	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	0.2	**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	0.3	**OVP**	0.17	0.05	0.05	0.05	0.05	0.05	0.05	0.05
C11	0.33	0.11	0.22	0.1	0.16	0.24	0.3	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	0.1	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	0.3	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	0.3	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 7
Cross-impact matrix.

	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**
G	−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

analysis of the distribution of the C_{ij} values (Table 8) that will help to select the most suitable cutting for the scenario creation (mentioned as "arbitrary value").

Taking the $P_{(50)}$ with an $C_{ij} > 2.1503$ as a reference has generated a CIA–ISM map of risks (Fig. 3) using the method described by Warfield in 1976, with the difference that the graphic representation has been carried out 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.

This illustration shows the relationships between all kinds of events. The white circles correspond to Cause Events and the 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 illustration is a risk map and shows all the events in 5 horizontal levels (the highest are event triggers) and presents two micro-scenarios, stressing that all the result events are a single micro-scenario. All the 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 acids), and C4 (SO_2 pollution) are trigger events.

Table 8
Percentile value table.

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

7. 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, the same as that which is mentioned in the methodological background section.

$$P_i = 1/\left[1+\exp\left(-G_i - \sum_{i \neq k} C_{ik} P_k\right)\right] \qquad (1')$$

To generate a prediction for all combinations of occurrence or non-occurrence for all the elements would be too great. This paper therefore 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 (personal accident). As well as the chain of related events, C1 → C2 → [R1, R2, R3, R4, R5, R6] builds 3 simulated scenarios. Fig. 4 shows the modified Cause Events (C1, C2) using a gray color.

Table 9 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.

- Scenario C would correspond to the Original model. It serves as a comparison.
- Stage I to an Explosion/Fire with personal accident.

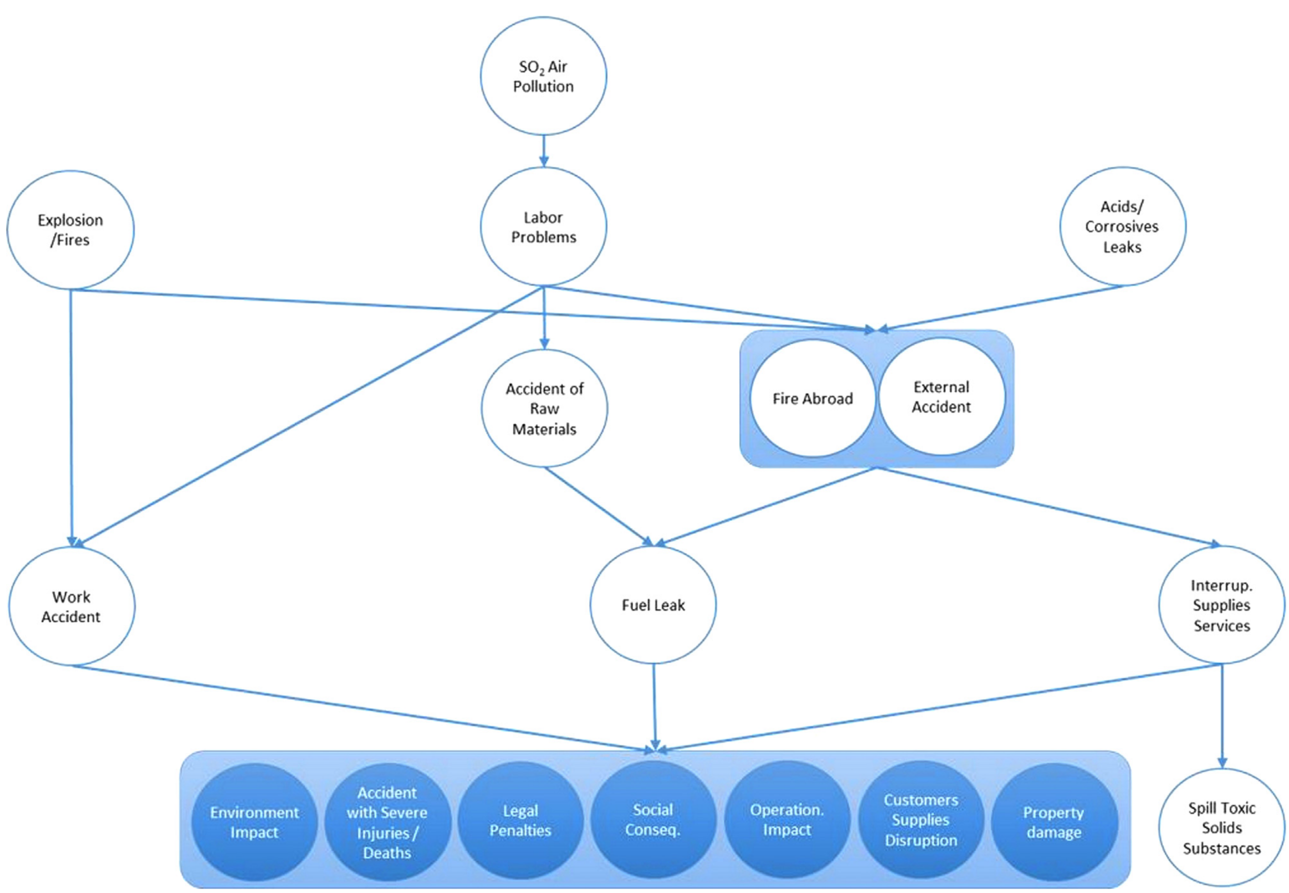

Fig. 3. $C_{ij} > 2.1503$ Digraph.

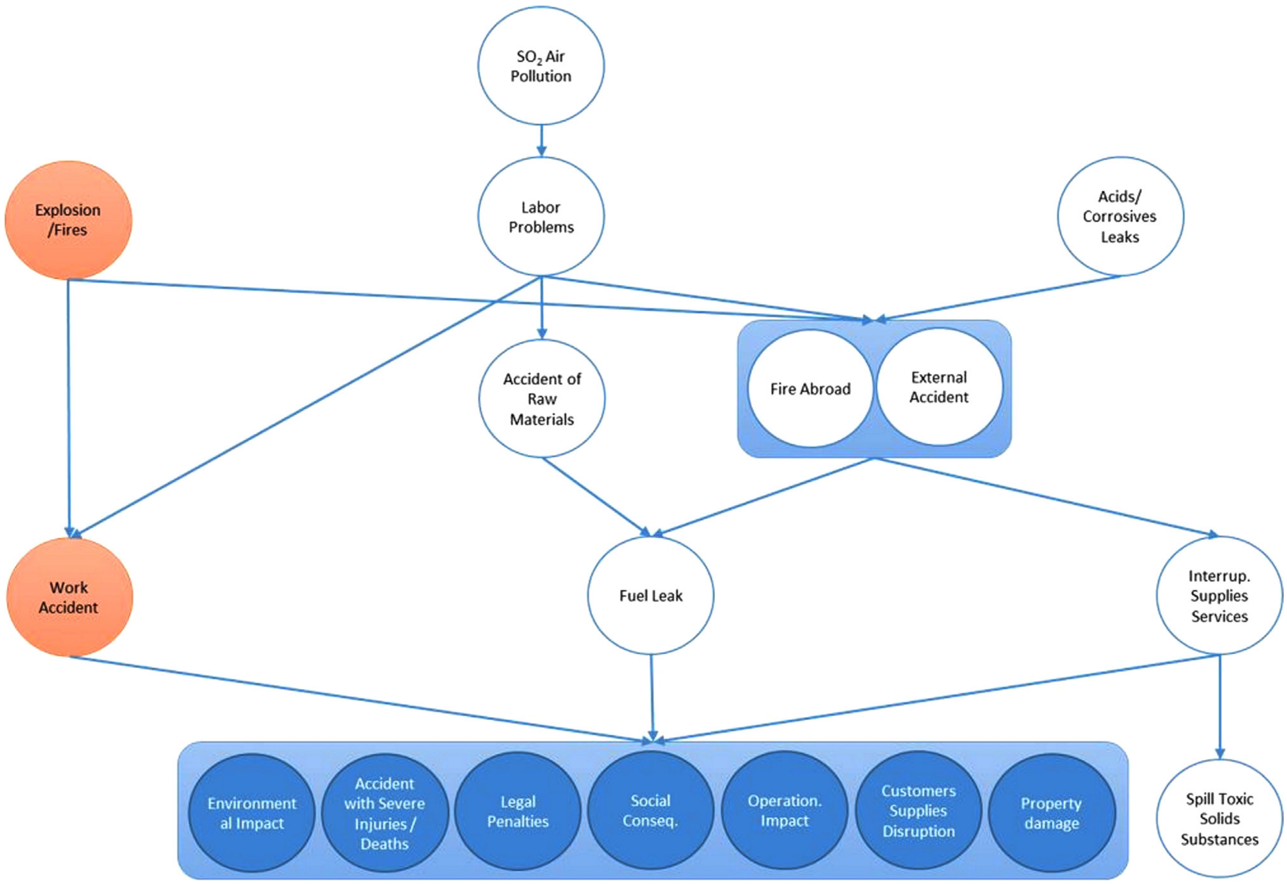

Fig. 4. $C_{ij} > 2.1503$ Digraph (Events Cause marked to forecast).

Table 9
Event cause per scenario.

	C1	C2	Rs
Scenario C	?	?	?
Scenario I	1	1	?
Scenario II	1	?	?
Scenario III	1	0	?

- 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. The following paragraphs explain the scenarios and the numerical results are presented in Table 10.

Table 10
Forecasted probabilities per scenario.

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%**	**R1**	**75.00%**	**R1**	**75.00%**	**R1**	**75.00%**
R2	**1%**	**R2**	**91.67%**	**R2**	**25.00%**	**R2**	**9.41%**
R3	**1%**	**R3**	**91.67%**	**R3**	**25.00%**	**R3**	**9.41%**
R4	**1%**	**R4**	**63.46%**	**R4**	**25.00%**	**R4**	**16.13%**
R5	**1%**	**R5**	**93.99%**	**R5**	**75.00%**	**R5**	**63.38%**
R6	**1%**	**R6**	**25.00%**	**R6**	**25.00%**	**R6**	**25.00%**
R7	**1%**	**R7**	**75.00%**	**R7**	**75.00%**	**R7**	**75.00%**

7.1. 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.

7.2. 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.

7.3. 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.

7.4. CIASS

All previous simulations can be simulated “live” using the CIASS web-tool. As is explained in the methodological background section, after uploading and saving the events definitions and the Impact Matrix on the web, all users who access them can simulate scenarios just changing the event odds. CIASS is really easy to use and does not need any previous knowledge about the method. All the results showed by CIASS use double indicators: percentages and colors. This tool is still at the development stage, and the developer team is working on adding more functionalities as ISM digraphs representations. As an example we will show the same simulations that we calculated but this time using CIASS (Figs. 5–7). All graphics show a comparative between the normal situation and that after disruption (simulated scenarios are shown in the columns under the Scenario title).

8. 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 had to 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”). Table 11 shows the questions asked and the arithmetic mean of the values of the 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 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.

9. CIA–ISM forecast in two consecutive time stages as a system to help in decision making.

Until now it has been described how the CIA–ISM methodology helps the organization to better understand the overall picture of organizational risk, based on the prior knowledge of the organization's security plans and the judgments of experts. But this knowledge can be used for making more effective and efficient decisions. As we explained before, the method allows us to see the obvious results as well to detect what is not obvious. The literature review shows that there are many authors who have written about the use of scenario method as part as of a decision support system (Comes et al., 2011; Montibeller et al., 2006). This section means to show how the CIA–ISM method could help us to manage the information and help us to make decisions.

One advantage of CIA–ISM is that it provides information from which we can obtain direct results of the simulation after the occurrence of an incident/accident (Fig. 4) and we can also predict the direct and indirect effects when an incident happens. The model we have obtained shows a dynamic scenario with multiple interactions between events. This means that when an accident/incident happens there will be consequences that will be aggravated if it is not resolved as quickly as possible. These consequences are not only for

Events — Scenario I: C1-C2

Type	Event N°	Event	Initial value	Hypothesis	Scenario	Hypothesis	Scenario
Dynamic	1	C1 - Explosiones/Incendios	0,2500	0,2500	0,2500	1,0000	1,0000
Dynamic	2	C2 - Accidentes Personales Graves	0,2500	0,2500	0,2500	1,0000	1,0000
Dynamic	3	C3 - Fuga de Ácidos Corrosivos	0,2500	0,2500	0,2500	0,2500	0,7114
Dynamic	4	C4 - Contaminación aérea por SO2	0,7500	0,7500	0,7500	0,7500	0,8500
Dynamic	5	C5 - Problemas laborales	0,7500	0,7500	0,7500	0,7500	0,9300
Dynamic	6	C6 - Incendios con efectos en el exterior	0,0500	0,0500	0,0500	0,0500	0,4672
Dynamic	7	C7 - Interrupción de suministros	0,0500	0,0500	0,0500	0,0500	0,8610
Dynamic	8	C8 - Accidente de materias primas	0,0500	0,0500	0,0500	0,0500	0,3282
Dynamic	9	C9 - Accidentes externos	0,0500	0,0500	0,0500	0,0500	0,5501
Dynamic	10	C10 - Fuga de fuel al mar	0,0500	0,0500	0,0500	0,0500	0,3434
Dynamic	11	C11 - Derrame de sustancias tóxicas	0,0500	0,0500	0,0500	0,0500	0,5345
Result	12	R1 - Impacto ambiental	0,0100	0,0100	0,0100	0,0100	0,7500
Result	13	R2 - Accidentes/Lesiones graves/muerte	0,0100	0,0100	0,0100	0,0100	0,9166
Result	14	R3 - Sanciones penales/legales	0,0100	0,0100	0,0100	0,0100	0,9166
Result	15	R4 - Consecuencias sociales	0,0100	0,0100	0,0100	0,0100	0,6346
Result	16	R5 - Impacto en operaciones	0,0100	0,0100	0,0100	0,0100	0,9398
Result	17	R6 - Interrupción suministro a clientes	0,0100	0,0100	0,0100	0,0100	0,2499
Result	18	R7 - Daños a la propiedad	0,0100	0,0100	0,0100	0,0100	0,7499

Fig. 5. CIASS Scenario I.

Events — Scenario II: C1-?C2

Type	Event N°	Event	Initial value	Hypothesis	Scenario	Hypothesis	Scenario
Dynamic	1	C1 - Explosiones/Incendios	0,2500	0,2500	0,2500	1,0000	1,0000
Dynamic	2	C2 - Accidentes Personales Graves	0,2500	0,2500	0,2500	0,2500	0,6845
Dynamic	3	C3 - Fuga de Ácidos Corrosivos	0,2500	0,2500	0,2500	0,2500	0,6137
Dynamic	4	C4 - Contaminación aérea por SO2	0,7500	0,7500	0,7500	0,7500	0,8285
Dynamic	5	C5 - Problemas laborales	0,7500	0,7500	0,7500	0,7500	0,8313
Dynamic	6	C6 - Incendios con efectos en el exterior	0,0500	0,0500	0,0500	0,0500	0,2368
Dynamic	7	C7 - Interrupción de suministros	0,0500	0,0500	0,0500	0,0500	0,6742
Dynamic	8	C8 - Accidente de materias primas	0,0500	0,0500	0,0500	0,0500	0,1755
Dynamic	9	C9 - Accidentes externos	0,0500	0,0500	0,0500	0,0500	0,2696
Dynamic	10	C10 - Fuga de fuel al mar	0,0500	0,0500	0,0500	0,0500	0,1856
Dynamic	11	C11 - Derrame de sustancias tóxicas	0,0500	0,0500	0,0500	0,0500	0,3334
Result	12	R1 - Impacto ambiental	0,0100	0,0100	0,0100	0,0100	0,7500
Result	13	R2 - Accidentes/Lesiones graves/muerte	0,0100	0,0100	0,0100	0,0100	0,2500
Result	14	R3 - Sanciones penales/legales	0,0100	0,0100	0,0100	0,0100	0,2500
Result	15	R4 - Consecuencias sociales	0,0100	0,0100	0,0100	0,0100	0,2500
Result	16	R5 - Impacto en operaciones	0,0100	0,0100	0,0100	0,0100	0,7500
Result	17	R6 - Interrupción suministro a clientes	0,0100	0,0100	0,0100	0,0100	0,2499
Result	18	R7 - Daños a la propiedad	0,0100	0,0100	0,0100	0,0100	0,7499

Fig. 6. CIASS Scenario II.

Events — Scenario III: C1- No C2

Type	Event N°	Event	Initial value	Hypothesis	Scenario	Hypothesis	Scenario
Dynamic	1	C1 - Explosiones/Incendios	0,2500	0,2500	0,2500	1,0000	1,0000
Dynamic	2	C2 - Accidentes Personales Graves	0,2500	0,2500	0,2500	0,0000	0,0000
Dynamic	3	C3 - Fuga de Ácidos Corrosivos	0,2500	0,2500	0,2500	0,2500	0,5784
Dynamic	4	C4 - Contaminación aérea por SO2	0,7500	0,7500	0,7500	0,7500	0,8209
Dynamic	5	C5 - Problemas laborales	0,7500	0,7500	0,7500	0,7500	0,7797
Dynamic	6	C6 - Incendios con efectos en el exterior	0,0500	0,0500	0,0500	0,0500	0,1800
Dynamic	7	C7 - Interrupción de suministros	0,0500	0,0500	0,0500	0,0500	0,5895
Dynamic	8	C8 - Accidente de materias primas	0,0500	0,0500	0,0500	0,0500	0,1389
Dynamic	9	C9 - Accidentes externos	0,0500	0,0500	0,0500	0,0500	0,1985
Dynamic	10	C10 - Fuga de fuel al mar	0,0500	0,0500	0,0500	0,0500	0,1473
Dynamic	11	C11 - Derrame de sustancias tóxicas	0,0500	0,0500	0,0500	0,0500	0,2749
Result	12	R1 - Impacto ambiental	0,0100	0,0100	0,0100	0,0100	0,7500
Result	13	R2 - Accidentes/Lesiones graves/muerte	0,0100	0,0100	0,0100	0,0100	0,0941
Result	14	R3 - Sanciones penales/legales	0,0100	0,0100	0,0100	0,0100	0,0941
Result	15	R4 - Consecuencias sociales	0,0100	0,0100	0,0100	0,0100	0,1612
Result	16	R5 - Impacto en operaciones	0,0100	0,0100	0,0100	0,0100	0,6337
Result	17	R6 - Interrupción suministro a clientes	0,0100	0,0100	0,0100	0,0100	0,2499
Result	18	R7 - Daños a la propiedad	0,0100	0,0100	0,0100	0,0100	0,7499

Fig. 7. CIASS Scenario III.

results, these effects would multiply, affecting other events causes and leading to a chain reaction in which results affect other events which were not considered at first.

In the following lines we describe an example about how CIA–ISM forecast could help us to detect some non-obvious effects and help us to make better decisions. We know that an explosion has

Table 11
Expert satisfaction 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

immediate direct effects, such as Property Damage, Serious Personal Injuries and Operation Impacts, etc. Moreover, this is not surprising considering that this explosion could trigger a Fire Abroad that would have its own consequences, for example damaging an Acid deposit and causing a leak with the possible repercussion of Environmental Damage. In any case, these last events would not be observable with a direct prediction and this forces us to make a dynamic prediction. As we explained previously, the CIA–ISM method could be used to make predictions that show the direct effects after some event (or events) has (have) happened. But that just shows us a direct prediction after an accident (first stage). To know what happened with our model in the future we need to extend the forecasting method beyond that first step, where Stages must be understood as temporal stages. Stage 1 or Step 1 is the temporal stage after one incident happened, and Step 2 (Stage 2) is the following temporal stage.

In other words, there are a number of relatively clear results after the occurrence of an accident. These results are its direct consequence and are usually defined in the safety and security plans. But in a second stage (Step 2) we can find no obvious results that must be considered when in the decisions process to minimize risks. The following is an example illustrating this problem in our study.

If the purpose of a safety plan and protection is to minimize the risk to workers over any other type of either economic or environmental risk we must consider whether there is any event that would cause a greater risk to the lives of workers which is not so immediate. Our aim therefore is to see what happens to the R2 indicator (Severe Injuries/Deaths), simulating the occurrence of each of the events as has been done in the previous simulation section. Now we generate 11 different scenarios forcing all Event Cause to happen one by one and we evaluate the obvious results (Step 1) upon the occurrence of each Event Cause separately. In a second phase (Step 2), we use the probabilities obtained by the initial simulation (Step 1) to recalculate again the 11 scenarios and explore if any of the events affect R2 in a non-obvious way.

Tables 12 and 13 show R2 observed probabilities calculated by the explained method for each of the two simulations. Step 1 shows the results in the first step of the simulation (the direct and obvious effects), and the Step 2 shows the second stage using the results of the simulation "Step 1" Initial Probability. The "Event" column indicates which event happen in the "Step 1" and column "R2 Prob." It tells us what is the probability of occurrence of R2 in each Stage (we showed numbers to see the differences but we must remember that we used a verbal scale). Both columns have been ranked by the probability of R2 from highest to lowest.

The occurrence of C1, C2 or C3 has direct implications for the occurrence of a possible accident with Serious Injury/Death (R2). After an explosion or accident it is the most logical obvious result. But if we look at the second stage (Table 13) we see two major changes. In the first one it is evident that a SO_2 Pollution will create a great cloud of polluting gas and this will damage the workers seriously. But what is more surprising is that the occurrence of Labor Issues (C5) increases the R2 value to 3rd place and has a 97.54%, higher occurrence than that of a Work Accident (C2), which has a rate of 75.95%. This may indicate that a lack of staff can have very negative effects in terms of the personal safety of workers.

Table 12
Stage 1 R2 Prob.

Stage 1			
#	***Event***	***Id.***	***R2 Prob. (%)***
1	Expl/Fires	C1	25.00
2	Acid. Leaks	C3	25.00
3	Work Acc.	C2	25.00
4	SO_2 Pollut	C4	5.00
5	Raw Material	C8	5.00
6	Fire Abroad	C6	5.00
7	External Acc	C9	5.00
8	Spill Toxic	C11	5.00
9	Labor Probl.	C5	1.00
10	Interrp. Suppl	C7	1.00
11	Fuel Leak	C10	1.00

Table 13
Stage 2 R2 Prob.

Stage 2			
#	***Event***	***Id.***	***R2 Prob. (%)***
1	Expl/Fires	C1	99.90
2	SO_2 Pollut.	C4	97.90
3	**Labor Probl.**	**C5**	**97.54**
4	Acid Leaks	C3	96.77
5	Raw Mat. Acc.	C8	95.50
6	Fire Abroad	C6	87.93
7	Work Acc.	C2	75.95
8	External Acc.	C9	71.69
9	Interrp. Suppl	C7	49.09
10	Spill Toxic	C11	37.90
11	Fuel Leak	C10	21.56

Therefore, when making decisions that help to minimize the risk of Serious Injuries/Deaths (R2), we must consider that the C5 (Labor Problems) event may propose changes to the system of compulsory minimum services to be met in the event of a strike in order not to endanger the life of other employees, including those who are in the vicinity of the plant.

As mentioned previously, the probability of R2 Serious Injury/Death happening after the occurrence of Labor Problems (C5) is higher in a second phase (Stage 2) than when a Work Accident (C2) happens, but the results are not limited to this Event Result. If a Labor Problem (C5) happens, the probability of the occurrence of all Events Results are really high and trigger a totally catastrophic scenario (Table 14).

We must explain now why this occurs. First of all it is necessary to explain that these Labor Problems are not just a simple confrontation between workers and the organization, these problems must be severe, such as a long strike or a really strong conflict between the workers and the organization. As there is some literature about how labor problems such as staff shortages may negatively influence workers safety (Papazoglou et al., 2003), this perhaps cannot be considered as unexpected for the literature, but in this real case we can say that the organization is unprepared to deal with this problem, and this analysis detects this situation.

It is true that the C5 Event does not impact directly on R2. The CIA Matrix shows no impact. But the C5 column (Table 15) shows a really high score over the rest of events (as an example of risks interactions). If we carry out a summary of C_{ij} by each column, it is easy to observe that the C5 column shows the highest value.

Table 14
Work accident and labor problem predictions.

Work accident (C2)			*Labor problems (C5)*		
	Stage 1	***Stage 2***		***Stage 1***	***Stage 2***
C1	34%	49%	***C1***	32%	49%
C2	100%	100%	***C2***	45%	75%
C3	34%	51%	***C3***	32%	52%
C4	78%	86%	***C4***	83%	88%
C5	89%	93%	***C5***	100%	100%
C6	13%	43%	***C6***	11%	45%
C7	14%	74%	***C7***	31%	84%
C8	11%	39%	***C8***	16%	48%
C9	15%	58%	***C9***	16%	68%
C10	11%	49%	***C10***	16%	64%
C11	11%	51%	***C11***	16%	66%
R1	***1%***	***1%***	***R1***	***1%***	***1%***
R2	***25%***	***76%***	***R2***	***1%***	***98%***
R3	***25%***	***98%***	***R3***	***25%***	***99%***
R4	***5%***	***99%***	***R4***	***75%***	***99%***
R5	***5%***	***99%***	***R5***	***75%***	***99%***
R6	***1%***	***1%***	***R6***	***25%***	***99%***
R7	***1%***	***11%***	***R7***	***1%***	***85%***

So this means that there is not a direct effect of C5 on R2 in a first Stage, but there are many indirect effects. Using another method to explain this, we can see in Fig. 8 how C5 is extremely related to most events (Causes and Results). We used the $P_{60}(C_{ij})=2.6561$. The elaboration of this digraph shows how C5 impacts on R2 (C6, C7, C8). As is mentioned in the previous paragraph, the relationship between labor problems and safety is not new, but in this case the organization knows the nodes between both events using the correlations calculated with CIA.

From these results, we can say that using CIA–ISM provides us with the ability to detect non-obvious results which help us to consider different scenarios that could hardly be considered directly. Hence we can assess complex scenarios and use them to support decision making. In this particular case the organization should consider the effects of a labor problem over and above other types of events, considering the importance of the occurrence of C5 and its implications. It will thus note these events with greater emphasis when making decisions about the serious personal risks of mitigation plans.

10. Conclusions: limitations and future research

This paper has been the first development of an industrial risk map based on HAZOP and the Risk Consequence Matrix plus CIA–ISM, considering all possible risks interactions (it is not an individually risk analysis), categorizing risks by importance, showing the cascading effects and identifying the micro-scenarios generated. We have illustrated how the combination of these methods help us to understand the big picture of Operational Risk Management in a complex organization with less information loss

Table 15
Ci sum. values.

Event	C1	C2	C3	C4	**C5**	C6	C7	C8	C9	C10	C11
Sum.	63.98	24.20	40.90	111.07	**113.99**	24.27	21.07	28.74	22.44	18.63	18.81

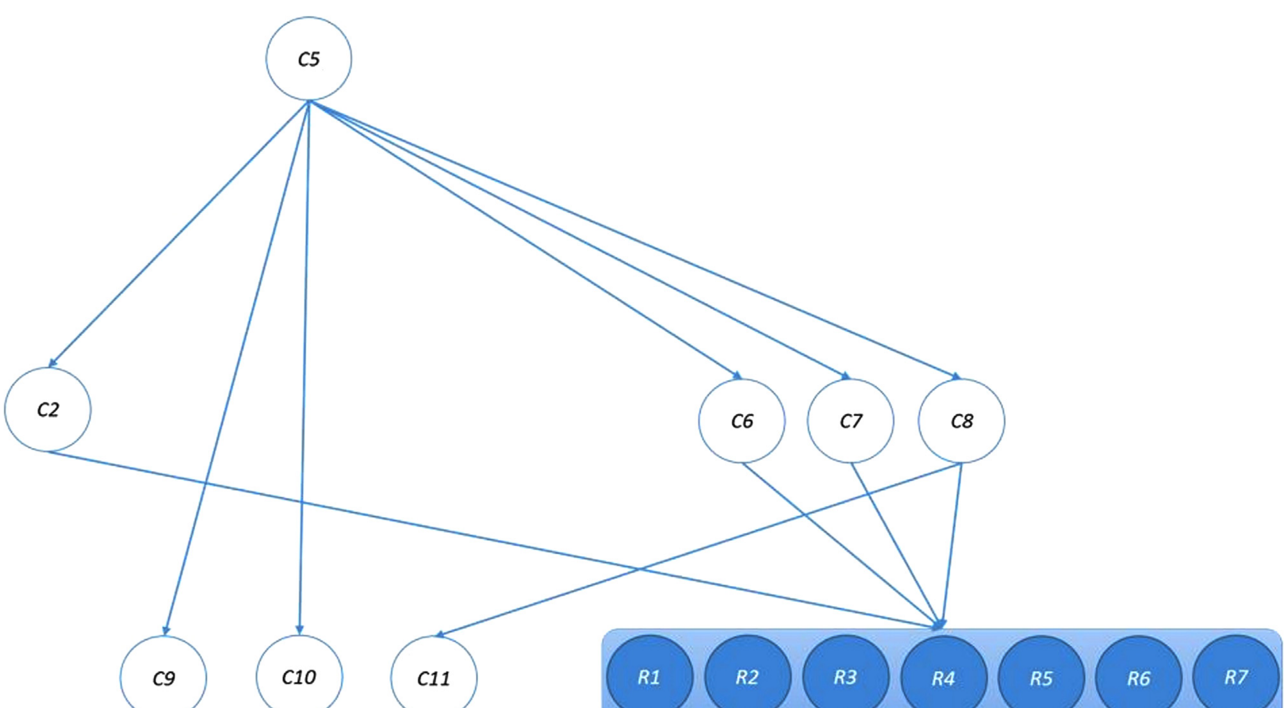

Fig. 8. Labor Problem (C5) Digraph (Percentile 60).

Table 16
Parts and output data (Tixier et al. (2002) conclusions).

Parts	Output data
The source (industrial establishment) The flux (vector of propagation) Targets (human, environmental and equipment) Control and management	Qualitative in order to provide recommendations Quantitative in order to evaluate the main consequences

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/unprepared 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 be 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 principles described by Weick and Sutcliffe (2007). As a 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. Being more specific with 5 Weick and Sutcliffe HRO principles:

- Preoccupied with failure: Using a more complete method that is currently used in industrial environments to identify potential risk situations, even those with a low probability.
- Reluctant to simplify: The most used methodologies for industrial risks analysis frequently analyze risks one at a time, however this one considers the combination of all risks. This is a way to avoid simplification.
- Sensitive to operations: The organization is able to elaborate a complete scenario with all the operations and not only with the most important ones. This is a way to help the organization to be more concerned and sensitive with all operations.
- Commitment to resilience: Being able to detect all kinds of relationships between risk events and evaluate the importance of these scenarios and all their elements is a way to enhance the level of the organization's resilience. The organization, for example, may use the forecasted scenarios to elaborate more precise security plans and train the personal to fight against the risk.
- Deference to expertise: This method considers all kinds of experts, not only top staff. The experts to be asked may be external and internal at all levels in the organization.

At this point we must refer once again Tixier et al.'s paper. In the conclusions they propose the main characteristic of a good risk analysis methodology (Table 16). The method must identify four parts in an exhaustive way and together with their interactions. “*Then a deterministic and probabilistic approach with a hierarchisation phase should be permitted and, finally, the output data could be of two different types*”.

Finally Tixier wrote that with these elements the methodology will provide some ways of improving and helping in decision making. In this paper we combine the previous knowledge of the organization itself (HAZOP and the Risk Consequence Matrix) and CIA–ISM. The result is a combination of methodologies that completes all parts: Source, targets and control may be explained by HAZOP and the Risk Consequence Matrix and flux by CIA–ISM. Qualitative Output data is provided by HAZOP and Quantitative Output data by CIA–ISM. We thus 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 organizations. 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.

In the last part of this paper we try to show how the combination of HAZOP and the Risk Consequence Matrix and the CIA–ISM method could help us in the Decision Process showing us non-obvious results more than if the organization uses only the first method. Our example shows how one event could in an indirect way affect others, being more important than we expected in the first stage. In this way the forecasting method reveals important information needed to make a better decision.

This research has some limitations. The size of the expert panel is reduced, being the minimum required by the literature, and only one round of questions was carried out. A multi-round Delphi process would add more valuable information. Notwithstanding, from our perspective these limitations do not have 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 contexts; 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.

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