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# Evaluation of Workers Accidents Through Risk Analysis

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Among the available methods for the analysis of accidents/injuries, the AEB approach (Accident Evolution and Barrier Analysis) and the 3CA-Form B method (Control Change Cause Analysis) have been used to analyze a typical accident, which often occurs, in which have been involved several workers that entered in a confined space containing toxic and/or inert gases, causing the workers death. A critical analysis of the investigated methods has been performed in order to identify the best available methodology; in particular, it was evidenced a problem of events representation with the AEB method because the large part of the causes was due to human factors, so the entire sequence of the events that led up to the accident is represented in a linear way, on a same column, by this approach making difficult to relate events that took place simultaneously. The 3CA-Form B method allows, on the other hand, a good description of the events sequence taking into account simultaneously all aspects and issues, both human and technical, that characterize it.

## 1. Introduction

Risk analysis techniques are generally applied to major incidents that can cause large consequences and damages. However, workplace incidents that produce accidents are a phenomenon which globally cause more damages than a single major incident; in Italy there are nearly one million of accidents per year of which about a thousand produce fatalities (INAIL, 2010; European Commission, 2009).
A risk analysis that is able to highlight what have been the primary events that led to the accident, would strongly help to put into practice prevention measures aimed to reduce future similar events.
A typical accident, which often occurs, is the one which involves workers that enter in a confined space containing toxic and/or inert gases, causing the workers death. One of these accidents has been analyzed in this paper through different methods for accident investigation; a critical analysis of the investigated approaches has been performed in order to identify the best methodology.

## 2. Methods for accidents investigation

Among the available methods for the analysis of accidents/injuries (Aven et al., 2006; Sklet, 2004; Sklet et al., 2006), the AEB approach (Accident Evolution and Barrier Analysis) and the 3CA-Form B method (Control Change Cause Analysis) have been used to analyze the case-study.

### 2.1 AEB method

The AEB method (Hollnagel, 1999; Svenson, 2001) describes an injury as a series of iterations between humans and technical systems that can determine a sequence of events (failures, malfunctions or errors) that can lead to an accident. Analyzing the events sequence it is then possible to define barriers (barrier functions) that could prevent or mitigate the accident and its consequences. The AEB model offers three different barriers: physical, technical and organizational, respectively.

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The accident is analyzed to produce a block diagram showing the logical sequence of the events (Figure 1). The events are usually divided into two columns, one for human factors, the other one for technical matters; a third column is used for the comments that should help to describe in a more comprehensive way some events or to specify some important factors such as barriers.
Workers can be included in the analysis both as recipients of the accident consequences and as a possible cause of the event. In the column related to human factors will be then inserted all the workers actions which cause the evolution of both the event and the subsequent changes. In this part of the model, the Performance Shaping Factors (PSF) must be considered (they represent conditions such as time, pressure and tiredness that affect human performance) if they established or contributed to the sequence of human errors. In the column of technical errors the equipments malfunctions or failures are described so as the deviations from normal operating conditions.
The barriers represent all systems that can stop the incident evolution; a barrier can be represented by an emergency control, by a physical protection, by a procedure or by an operator. One of the main goals of the AEB analysis is to identify errors related to the barriers and to suggest how these barriers can be improved or where to put additional protections.

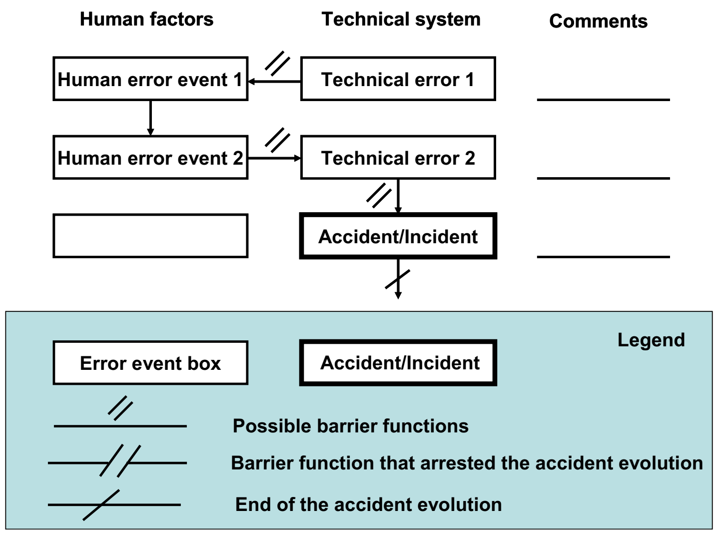


*Figure 1: Sketch of the AEB analysis.*

**2.2 3CA Model**

The 3CA method describes, in a concise and definite manner, accidents and injuries as a sequence of events in which undesirable changes occur. Different versions of the model 3CA are available: the first one, named 3CA - Form A (2002), the second one called 3CA - Form B (2009), which was developed from the previous version updating it, making it easier and more intuitive, and the third version, called 3CA - Form C (2010), which introduces the use of graphical worksheet to support the B-form of 3CA. This was written-up (a worksheet and a procedure) as an appendix to the B-form manual. However, as the graphical approach is for some users the main way of applying 3CA routines, the authors decided to produce a dedicated manual – the C-form of 3CA.
In this study, the Form B version have been used, because it allows for describing each identified event in terms of who or what produced the action, the action itself and who or what has been involved by the considered action. This makes possible to describe and analyze all the elements involved into the accident from the prevention point of view. With reference to Figure 2, firstly column 1, "significant events", must be filled with those events which significantly increase the risk and/or lower the possibility to control the accidental event, always taking into account: who or what is producing the action; what characterizes the action; what is affected by the action. Once highlighted relevant events, which are able to determine an increased risk or a loss of control of the sequence determining the accident/injury,

it is required to identify measures that could prevent the occurrence of these significant events or at least reduce their damages in the case these measures were ineffective (column 2). After the analysis, it will be necessary to decide which barriers and controls should be reasonably introduced for the investigated event. Continuing the analysis, column 3 must be filled; it identifies, for each accident/injury, the priorities; if the investigated case is particularly complex, it is necessary to analyze all the events that led to the injury. If the case is simple, it is possible to choose to analyze only the most important event in order of importance. Then, at column 4, it is possible to highlight the differences between what actually happened (accident) and what should have happened if the necessary safety procedures had been applied, so enabling to understand what was missing or what did not worked properly; this is crucial to prevent the same accident in the future. At the end, the last column (divided into three sections) must be filled; here the differences between the current state and the situation that would occur if barriers and controls were present are explained. It will be then necessary to review barriers and controls identified in column 2 and to decide which of these can be implemented as a protective measure in order to improve the safety of the entire process.

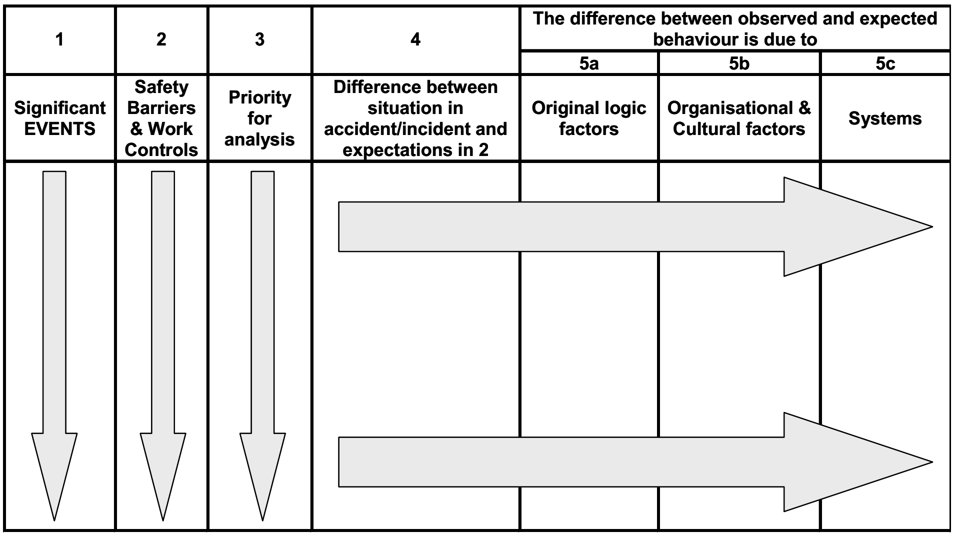


*Figure 2: Typical representation of the table that must be filled during the 3CA – Form B analysis*

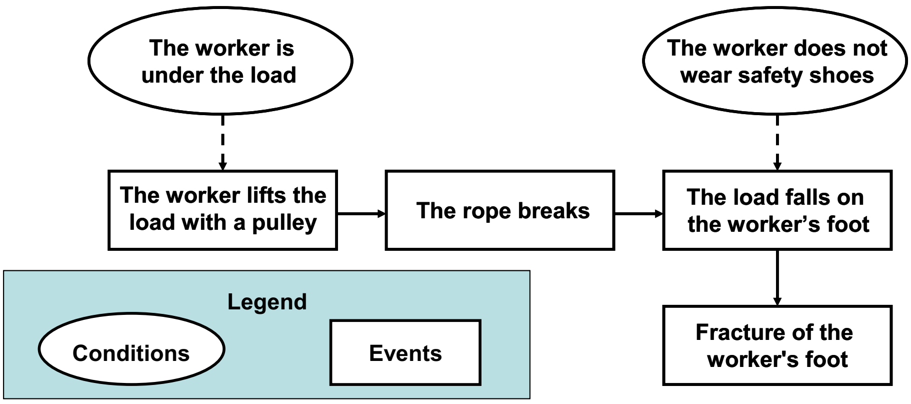


*Figure 3: Example of ECFA representation*

In order to support the 3CA technique, to ensure completeness in the analysis and to avoid forgetting several events or actions, a sequential method for the investigation of the events should be used. The

model proposes the use of the Event and Conditional Factors Analysis (ECFA) method (Buys and Clark, 1995; ECFA, 2007) to perform a detailed analysis of the events that characterize the investigated case. This part of the analysis is essential because the following steps of the method 3CA - Form B depend on the events that has been found and on their effective representation.
The integration of the 3CA – Form B method with the ECFA technique does not change the results of the 3CA analysis but basically it summarizes the results, thus improving their readability, as shown in the example of Figure 3 where in a simple and linear way the events evolution through the occurrence of certain conditions are highlighted. EFCA has the main aim to identify changes in the activity and to describe these events as a function of three factors: the actor who performs the change, the action that produces such a change, the item changed. It must be also identified those conditions that altered the normal sequence of the working process. The difference between events and conditions is that events are active elements while conditions are passive.

## 3. Results and discussion

The two above mentioned methods have been used to analyze a complex accident that involved six people, four of which died.

### 3.1 Case-study

Worker (A) was engaged in the washing of a tank used to transport chemicals; this tank was used to transport liquid sulphur. At 15:00, using a ladder, he climbed on the roof of the tank reaching the tank hatch. Before to wash the tank with a hot water jet to remove some pieces of solid sulphur, worker (A), via a ladder positioned inside the tank, started to go down into the same; during this action he lost consciousness falling inside the tank storage. On the basis of the evidences given by worker (S), who survived the accident, it is possible to know that (A) was the only one involved in the tank clean-up operations; moreover, (S) spoke with (A) at 15:10 while (A) was on the tank roof. Then (S), engaged with workers (B) and (C) in other activities, moved to another site of the plant yard, away from the washing area. After a few minutes he noticed also the absence of (B) and (C); so, worried by this fact, he moved towards the washing area, where he noticed the absence of the three colleagues. After having ascended on the tank roof, facing the hatch, he saw the bodies of his three colleagues on the tank floor. He started requesting for some help and the daughter of the company owner and worker (D), employee of a third party company, were alerted by his requests; (D) quickly climbed on the tank roof and descended inside the same with the aim to aid people who were laying there but, after a first attempt, he also lost consciousness. Few minutes later, the company owner (T) still reached the site and he suddenly decided to descend into the tank. Once (T) have reached the tank floor, he started to lift the body of one of the workers but, after a few moments, even him began to have some problems, thus loosing consciousness. Finally, at around 16:00 hours, came on-site the fire brigade; firemen intervention allowed to rescue just one worker, while four of them died in the accident.
Nevertheless this accident looks like an incredible situation, it is possible to notice unfortunately that it is similar to many others accidents which cause dozens of deaths each year.

### 3.2 Results with the AEB method

The accident reconstruction with the AEB technique (part of which is sketched in Figure 4) presents some difficulties of representation because the events sequence can be completely ascribed to human factors. A possible solution could be to split the accident description into four graphs, but this way it would be lost the right sequence of the events.
The analysis showed the total lack of organizational and technical barriers that could prevent or at least reduce the consequences of the accident. In particular, nobody at the plant site was informed about the substances that were contained into the tanks which had to be washed. Moreover, personal protective equipment were not available for the workers (in this case self-contained breathing apparatus), there was no operating procedure to enter the tanks and the presence of a second man to supervise actions into confined spaces was not required. Although workers that arrived later (including the owner) had seen the bodies on the tank bottom, they decided to go down without taking any precaution.

The major representation limit of this accident with the AEB method is due to the fact that the entire events sequence is described chronologically but in a linear way on the same plane; this makes difficult to relate contemporary events that occurred during the accident.

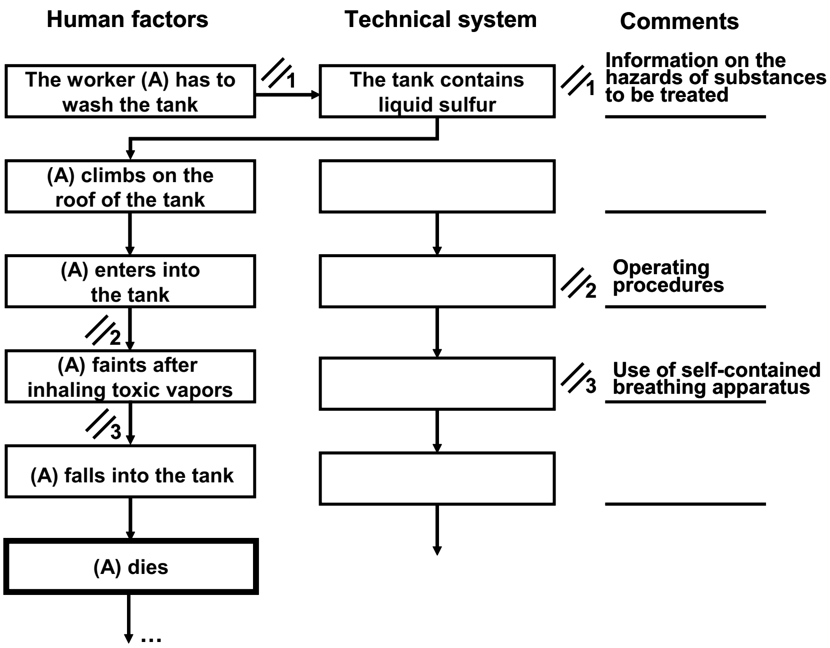


Figure 4: Case-study analysis with the AEB method

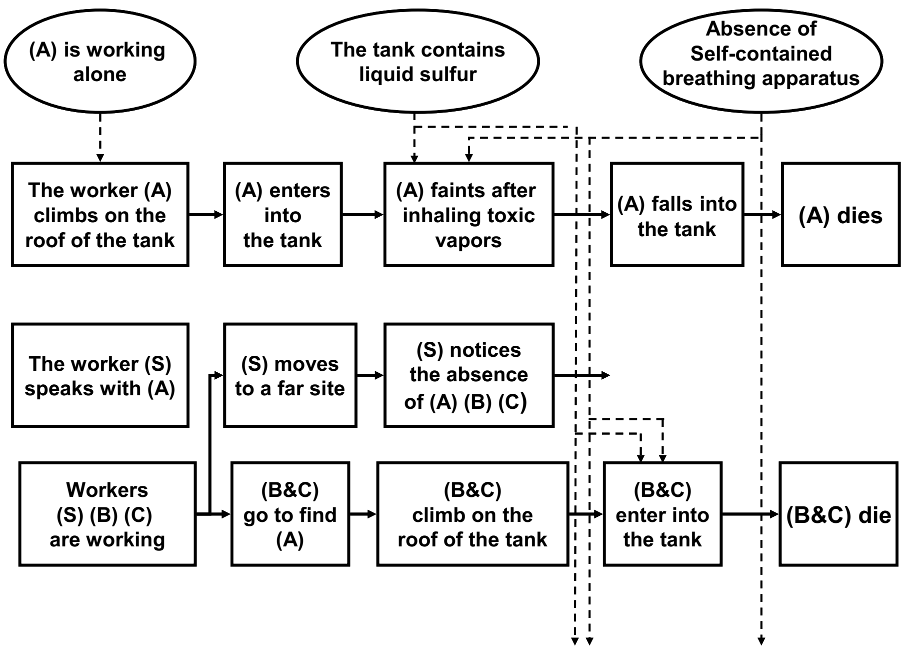


Figure 5: Case-study analysis with the ECFA model of the 3CA – Form B method

**3.3 Results with the 3CA model**

For the analysis with the 3CA - Form B technique, the accident events are described using the ECFA model (part of which is sketched in Figure 5); then the above mentioned table (Figure 2) must be filled. With reference to Figure 5, it can be noticed that it is possible to fill one line for each worker, or each group of workers, acting in the accident scenario, defining the temporal sequence of events. It is also possible to highlight the circumstances that influenced the events and when they did it.

Then, filling the table required by the method (here not provided due to space constrains) it was evidenced a number of deficiencies due mainly to human errors depending on the lack of training of workers, lack of procedures and the absence of any personal protective equipment. Note that the accident sequence was triggered by worker (A) that entered the tank unaware of the consequences arising from the presence of sulphur compounds. Other workers behaviour, who have seen the colleagues on the tank floor, highlights a complete lack of preparedness for an emergency situation.

The 3CA - Form B method adapted very well to the analysis of complex injuries with the simultaneous presence of several subjects, because the ECFA technique allows, for each subject, to represent into a plot the events in rows and the history in columns.

## 4. Conclusions

Applying the two risk analysis methods to a complex accident like the one here considered (6 people were involved, 4 of which died), some critical issues can be evidenced. Each of the two approaches required about one day (of which half day was needed to collect data related to the accident) to complete the case-study analysis. The AEB method can represent the accident sequence highlighting the relationship between human and technical factors; its graphical representation, however, presents some difficulties when there is the need to describe an event that is spread over different coordinates that overlap at some points. In the investigated case the AEB method fails to clearly represent both events that occurred simultaneously and actions of few workers.

The 3CA - Form B method (integrated with the ECFA technique) allowed to describe the events of the investigated accident in a simple and complete way. Indeed, it is possible to represent the different events sequences that take place at different times because the graphical approach of the ECFA technique makes possible to organize events related to the different subjects in rows and the chronology of events in columns. In the same chart, the points in which circumstances had effect can be highlighted.

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