CHEMICAL ENGINEERING TRANSACTIONS
VOL. 43, 2015
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Chief Editors: Sauro Pierucci, Jiří J. Klemeš

ISBN 978-88-95608-34-1; **ISSN** 2283-9216
DOI: 10.3303/CET1543204

Advanced Technique for the In-Depth Analysis of Occupational Accidents

Roberto Luzzi[a], Sara Passannanti*[b], Mario Patrucco[b]

[a]INAIL CONTARP Direzione Regionale Piemonte – Corso Orbassano 366, 10137, Torino, Italy
[b]Dipartimento di Ingegneria dell'Ambiente, del Territorio e delle Infrastrutture -DIATI-, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Torino, Italia;
sara.passannanti@polito.it

In spite of the growing attention towards Occupational Safety and Health OS&H, the enforcement of ECC directives, regulations and technical standards, and the improvements in techniques and technologies, in Italy an average of 3 daily work related fatalities is still recorded, mostly in not relevant risk industrial activities and at construction sites.
Since the limited knowledge of accident root causes, slapdash remedies, and occasional inspections are clearly inadequate to highlight and control the criticalities of complex activities, the first target should be an unbiased analysis of the causal chain of events that led to the accident.
The paper deals with the results of an extensive research work aimed to develop an original technique: the Computer-aided Cause Consequence for Prevention, evolved by a combination of Event Tree and Fault Tree Analysis. CCCP leads to focus on the intermediate and root causes of work-related accidents, reducing the possibility of errors due to subjective judgment or hasty evaluation, and the too easily reached conclusion of incorrect behavior of the victim.
The computer assisted approach allows the user: to a) identify the input data useful for the analysis, b) realize the sequence of the causes, c) identify flaws in the design and in the risk assessment, the non-compliances to regulations, and the lack of prevention measures.
Effective and suitable measures for prevention, both technological and organizational, can be introduced for similar cases or industrial situations.

1. Motivation of the study

The use of the statistical data about the occurred accidents was introduced on the basis of the research work carried out by Heinrich (1931), who suggested that prevention can be implemented on the basis of information on the frequency of deviations from a correct working situation. This approach led to the introduction of very large databases of occupational injuries and fatalities in many industrialized countries.
It should be underlined that Heinrich considered as main deviation the misconduct of the victims or colleagues, in spite of the obvious consideration that they are in direct contact with the hazard factor. As clearly discussed by Reason (2000), this way of thinking represents a "person approach" to the analysis of the accidents, generally incorrect and useless for future improvements of the safety of the system. In addition, Manuele (2011) contested the Heinrich approach, which is nowadays considered at least obsolete by the modern safety science.
According to these considerations, some databases (e.g. US DOL OSHA Agency) have critically evolved, also starting to list information on the violations of the safety standards.
However, some common misuses of the statistical data can lead to biased forecasting of expectable accident rates, and consequently produce important distortions in the prevention action. This is commonly due to one or more following causes:

1 – reduced statistical basis (at regional scale, without consideration of the local industrial situation),
2 – poor analysis of boundary data (e.g. economical and occupational situation),

Please cite this article as: Luzzi R., Passannanti S., Patrucco M., 2015, Advanced techniques for the in-depth analysis of occupational accidents, Chemical Engineering Transactions, 43, 1219-1224 DOI: 10.3303/CET1543204

3 – wrong range of time for the aggregation of the accident data, causing overestimation of catastrophic exceptional events.

So far the availability of statistical accident databases has stimulated numerous attempts of manipulations, both in a numerical and keyword approach, some of them producing real interesting results (e.g. based on analysis with clustering algorithms, fuzzy logic or statistical learning algorithms inspired by biological neural networks (Demichela et al, 2007). Moreover, in some cases a careful analysis of technological modifications can make available useful correlations (Camisassi et al., 2004).

Anyway, if the accident data bases are complete (and the violations of safety standards standard can be at least inferred if not directly available), and correctly used, they can be of great help: in fact, an effective inspection can be based on the Attention Index (A.I.), which focuses the inspector attention towards the more common violations. Nevertheless, it should be strongly underlined that in no case the A.I. should be misinterpreted as a Risk Index, as it causes incorrect Risk Analysis and Management.

Guidelines for the OS&H summarize the above depicted aspects: they are based on the expected frequency of occurrence level, which formalizes the idea that a zeroed or minimized risk is granted only by fulfilling up to date technical standards and safety and health regulations.

Such an approach presents however some limitations:

- an non-apodictic faith in the up to date technical safety standards, TLVs®, etc. is needed, the general principles being of no help;
- conditions not covered by detailed technical standards cannot be directly treated: this is taken into account in the aforesaid Guidelines, and some analysis techniques are suggested,
- the management of residual risks requires further special analysis covering new materials and substances, technical and organization progress, etc.

In conclusion, for an effective use of the aforesaid approach, Risk Analysis and Risk Management require a deep understanding of the preconditions leading to the very root causes of the work-related accidents (i.e. the initiating event/s) since the Hazard Identification stage. This certainly represents a demanding task, that no accident database can satisfy alone, since in the real working situations the chain of events is often so complex that the most serious criticalities may be concealed at first glance (the Iceberg analogy is commonly used to clarify this concept).

The CCCP technique proposed in the paper has specifically been conceived for the in-depth examination of single accidents and is not affected by the problems of data availability and quality, even if the national/foreign statistical data are still an eligible reference. Moreover, a two-way approach makes possible to analyze both the specific occurred accident, and to verify the expectable effectiveness of preventive measures in a large number of situations.

2. The CCCP approach

The presented original technique focuses on the Root Causes: the target of the analysis is not the direct cause of the accident, but the chain of indirect causes, which, in logically connected steps from the Top Event to the Root Causes, produced the accident.

Prevention countermeasures are sought after not only for single causes, but also for combinations of intermediate causes, so that a number of links can be developed correlating the possible indirect causes of the event to the corrective measures. A net of corrective measures is then created, among which it is possible to select some of the cause-intervention connections, to ensure the safety of the whole system.

The root causes adopted for the model are not focused on human errors and hazardous behaviors, and they grant that the analysis is developed according to a System Approach.

The peculiarity of the technique is the capacity of modelling the system both in backward sense following a chain of Intermediate Events in order to identify the Root Causes of a Top Event (in a FTA like approach) and in forward sense, starting from the Root Causes, and discussing about the most suitable prevention measures. Figure 1 shows a graphical demonstration: the two arrows depict the backward sense of investigation and the forward sense of prevention. The construction of the tree is not a linear process, but may imply a number of iterations before reaching a final configuration that adapts to the specific case.

The integrate software environment Infortuni sul lavoro (Work related accidents) - Root Causes translates the theoretical model into a useful computer guide. All the occurrences are strictly codified with the aim of making the analysis objective and free from ambiguity.

Infortuni sul lavoro is structured in 11 sections that synthesize a large number of different aspects of the context. The order of filling is dynamic and there is always the possibility to add or correct the information previously inserted. In addition, the selection of some options can condition the filling and determine the request of a more specific description of the topic.

Root causes is much more rigid and the order of filling is already fixed. Moreover, the choice is allowed only between controlled options. These restrictions ensure the total absence of subjectivity and help the user to go in deep in the analysis, asking a large number of questions and stressing the links between different events.

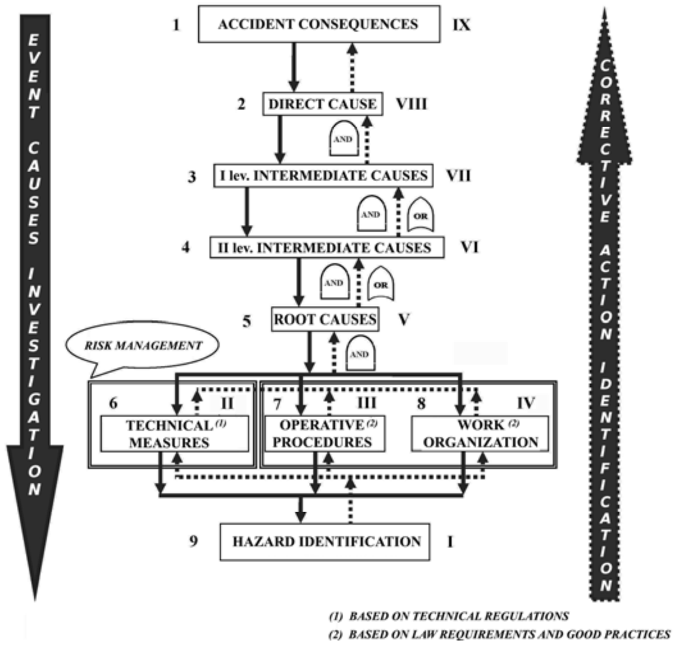

Figure 1: Logic flow chart of the model

The codification of options respects ESAW protocol.

Table 1: Categories of codification

Category of events	***References at the origin of elaborated lists***	***Number of possible associations***
Direct Cause	*ESAW*	*1*
I level Intermediate Causes	*ESAW*	*More than one*
II level Intermediate Causes	*Original elaboration*	*More than one*
Root Causes	*Original elaboration*	*More than one*
Macro-categories of Causes	*Principles of RAM*	*2, also simultaneous*

It is worth to note that compiling the forms is subjected to the quality and to the completeness of data in input. An application on a real case follows to provide a demonstration of the compilation process and the output of the model. Not all the forms are here presented, but just the most critical are stressed to understand the dynamic of accident and for the analysis.

3 A case history study

3.1. The here discussed accident

The here discussed accident occurred during the realization of a tunnel for a hydro plant. In particular, the victim was working on the lining with shotcrete while a block of cement dropped from the top of the wall and hit the worker, burying him.
The study of the Prosecutor investigation allowed to understand different circumstances related to the work environment and helped us to better understand the event and its cause tree. In fact, as showed below, the frame of the event is an inadequate work management, lacking of organization, technical and technological selection, and especially on occupational safety and health.
First of all, the existent document of risk assessment was compiled with computer assistance so the hazard identification technique used is likely a check list (see Figure 2). The evaluation of Severity of Damage (*ED)* and Probability of occurrence (*P)* were extracted from a risk matrix and the Contact Factor (*FC)* was not considered: a window on the page enhances that the evaluation of the risk is subjective. Furthermore, the

exposure model of workers is absent from the risk evaluation document, and the solution for management of risks cover just a few of processes.

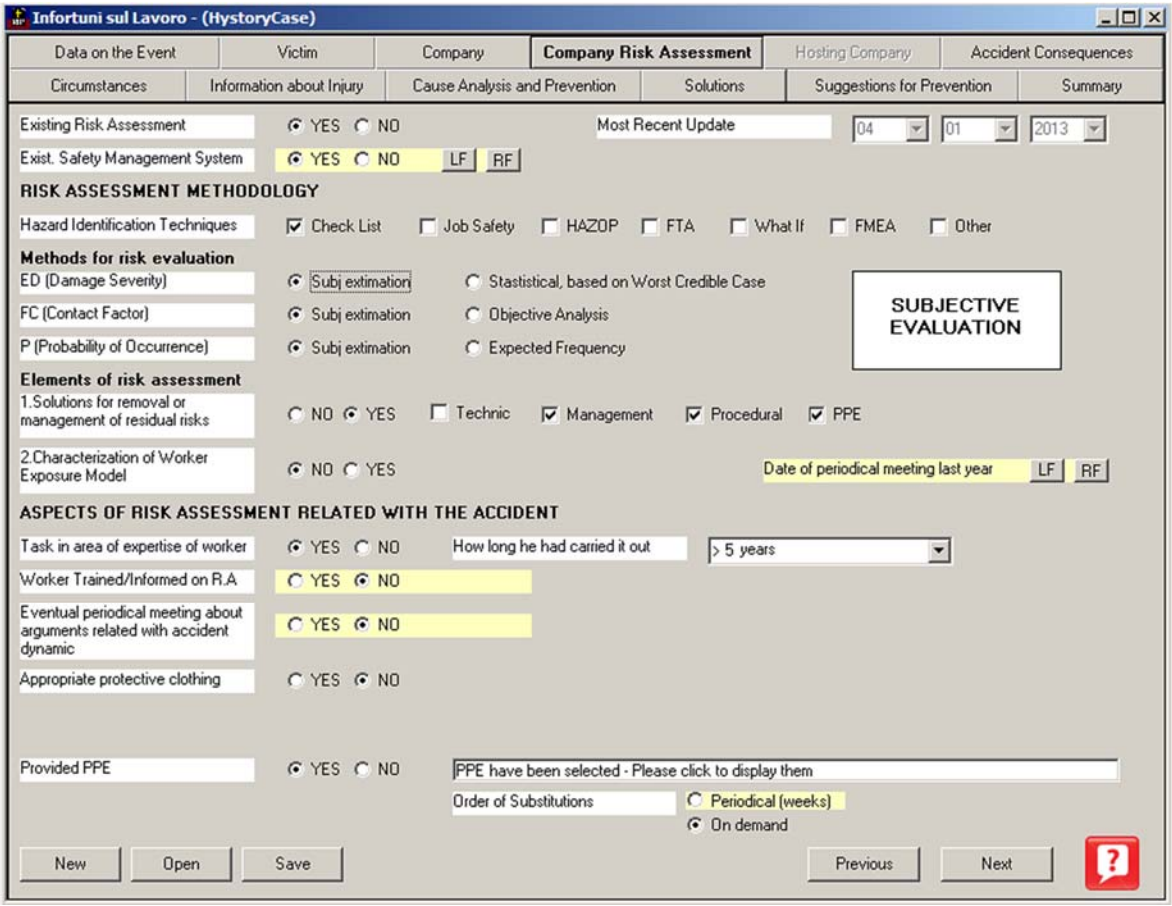

Figure 2: Risk Analysis Form in Infortuni sul Lavoro software (Note the presence of LF (load file) and RF (read file) commands, that allow to upload .pdf documents to the project so that analysis can be more complete).

3.2. Causes

The compilation of CCCP-RootCause permits the creation of a cause network, which is capable to represent complex cases, with multiple correlations too. Identified causes are showed in Table 2:

Table 2: Causes of the accident

For the falling of the cement block	***For the presence of the worker in the site of impact***
• General structural aspects; • Machine; • Supervision of working operations; • Procedures for machine operators.	• General systems for environmental conditions control; • Machine (again); • Functional volumes; • Procedures for workers.

The scheme obtained for the object of our study is presented in Figure 3. The letters on the scheme show if the causes are connected by AND-Gates or OR-Gates. The check indications define if causes are or are not necessary to the occurrence of the event (that is, to identify the Minimal Cut Set). This distinction is essential to understand the difference between the proposed measures of prevention.

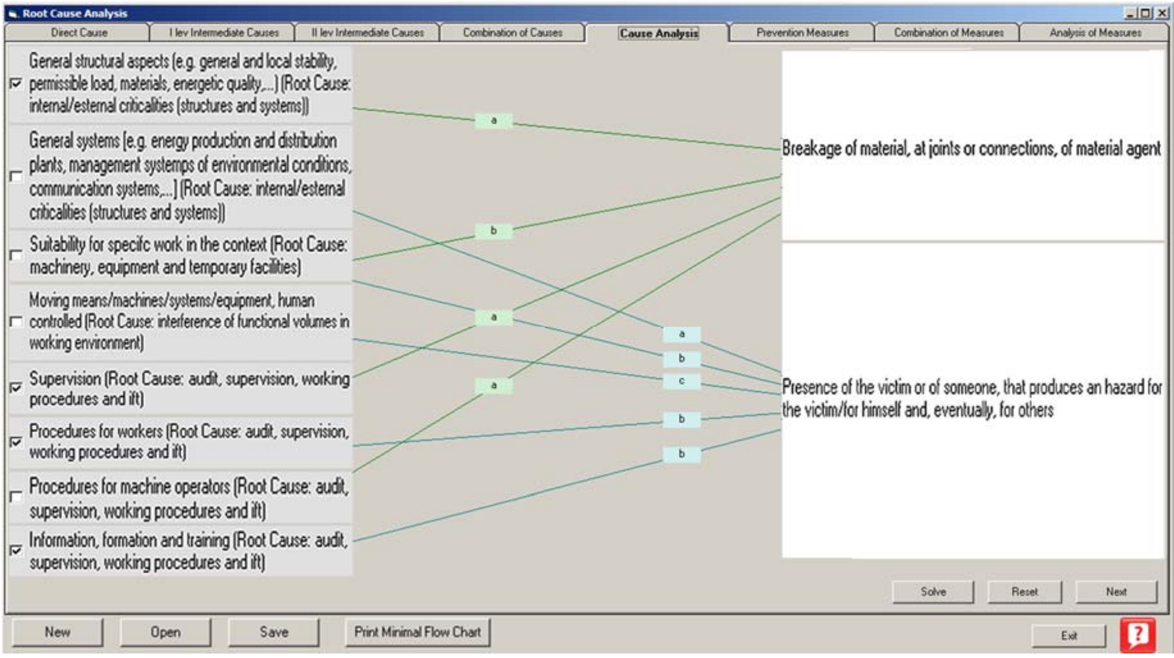

Figure 3: Causes Analysis Form in Root Cause software

3.3. Solutions

The model proposes two different solutions, not mutually exclusive but complementary (see Figures 4 and 5): on one hand, the minimal cut set is enhanced, and user can select the minimal solution set that solve it. In addition, causes solved with the same set of intervention are enhanced to underline the convenience in realizing such measures. On the other hand, as user identified all the root causes present in the system, it is important not to neglect any of them and to solve them all in order to make safe all the system and realize a more complete prevention.
CCCP-RootCause presents solutions in their general form (see Figure 6), so the analyst is invited to translate them into possible interventions that apply to the specific case.

ACCIDENT CONSEQUENCES *Internal injuries* *Multiple injuries* ↓ ***DIRECT CAUSE*** *Stucking, trapping, crushing under* ↓ ***I LEVEL INTERMEDIATE CAUSE*** *-Breakage of material, at joints or connection, of material agent* *-Presence of the victim that produces an hazard for himself* ↓ ***MINIMAL SET OF II LEVEL INTERMEDIATE CAUSES*** *-General systems* *-Suitability for specific work in the context* *-Moving means/machines/systems/equipment, human controlled* *-Procedures for machine operators* ***MINIMAL SET OF MEASURES OF PREVENTION*** *-Technical, structural and systemic solutions for work environment management* *-Technological/systemic solution to manage residual risks of specific working situations* *-Technological/systemic solution to manage interferences: specific working situations* *-Operational procedures for specific working situations* ***FURTHER CAUSES SOLVED BY MINIMAL SET OF MEASURES*** *-General structural aspects* *-Procedures for workers* *-Information, formation and training*	***ACCIDENT CONSEQUENCES*** *Internal injuries* *Multiple injuries* ↓ ***DIRECT CAUSE*** *Stucking, trapping, crushing under* ↓ ***I LEVEL INTERMEDIATE CAUSE*** *-Breakage of material, at joints or connection, of material agent* *-Presence of the victim that produces an hazard for himself* ↓ ***II LEVEL INTERMEDIATE CAUSES*** *-General structural aspects* *-General systems* *-Suitability for specific work in the context* *-Moving means/machines/systems/equipment, human controlled* *-Supervision* *-Procedures for workers* *-Procedures for machine operators* *-Information, formation and training* ***MEASURES OF PREVENTION*** *-Technological/systemic solution to manage residual risks of specific working situations* *-Definition of processes and stages for different workers at different levels* *-Operational procedures for specific working situations* *-Procedures for check, control and identification/warning/management of basic functional deviations*

Figure 4: Minimal Solution Chart *Figure 5: Complete Solution Chart*

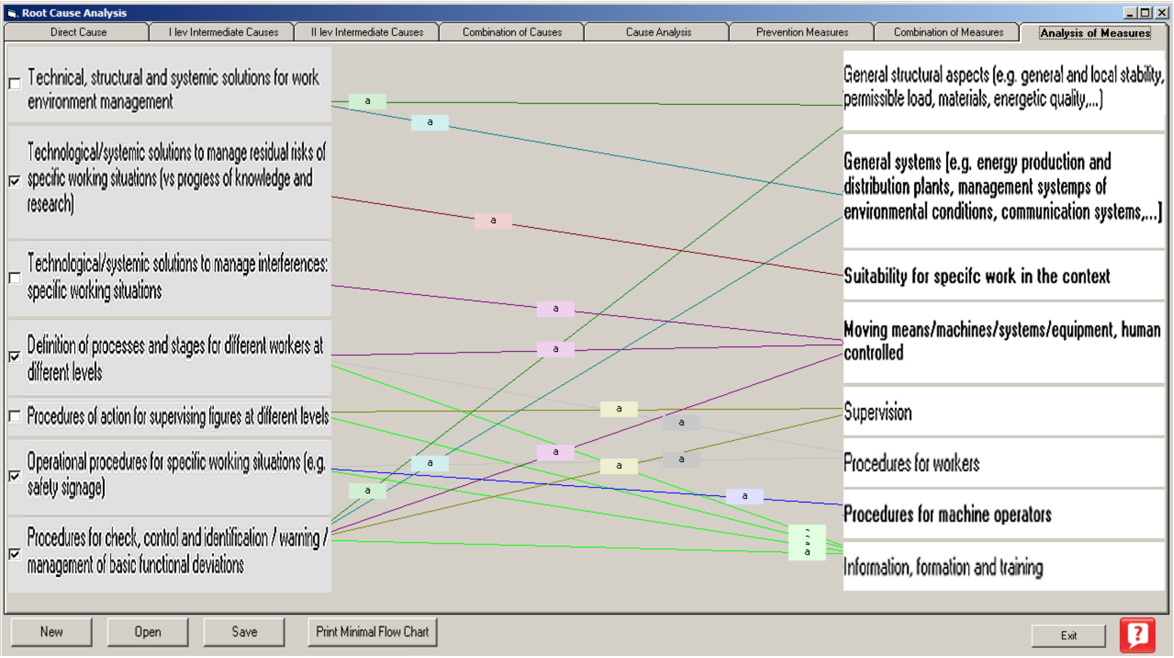

Figure 6: Solution Analysis Form in Root Cause software

4. Conclusions

In the present paper the original CCCP technique for in depth analysis of work-related accidents is discussed together with the related computer assisted system, both in general terms and with reference to a specific case. As demonstrated, the technique reduces the possibility of errors due to subjective judgments or hasty evaluations. The software is intuitive and user friendly, thanks to the presence of a number of pre-defined selection options (drawn, where possible, from widely used databases) for many of the involved parameters. Moreover, asides from some input data necessary to run the Root Cause subroutine, there is large flexibility in the completion of the information to be recorded in the various forms and it is possible to store in the project additional information in pdf format.

Aknowledgements

The research work was possible thanks to the support of the Italian assurance agency for work-related injuries INAIL (Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro).

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