The differentiation and decision matrix risk assessment of accident precursors and near-misses on construction sites

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Abstract—Precursors and near misses are well known for providing a major source of useful information for safety risk management. They are more frequent events than accidents and their causes may potentially result in an accident under slightly different circumstances. Despite the importance of this type of feedback, there is little knowledge on the characteristics of precursors and near misses, and on the use of this information in safety risk management. This paper focuses on differentiating the concepts of precursors related and evaluating the risk of precursors, near misses. First, precursors, near misses related concepts are reviewed and the relationships between the concepts are presented. Furthermore, the importance of precursors and near misses to further improve safety margins are emphasized. Eventually, risk-based evaluation of precursors, near misses is performed and the impacts of precursors, near misses on quantitative risk estimates are emphasized. By describing the precursors, near misses incidents with related probabilities and consequences, proactive management can be mobilized. Furthermore, a deeper understanding of the precursors and near misses will give the potential to control variability rather than by constraining it. Moreover, the investigation of precursors and near misses incidents can be used as a source of information for the construction of a structured methodological approach for decision-making. Information from precursors and near misses incidents investigations can also be important tools for improved risk communication.

Index Terms—Precursors, Near misses, Risk-based evaluation, Decision matrix.

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I. Introduction

Almost every year there is at least one technological disaster that highlights the challenge of managing technological risk. On February 1, 2003, the space shuttle Columbia and her crew were lost during reentry into the atmosphere. In the summer of 2003, there was a blackout that left millions of people in the northeast United States without electricity. On March 23, 2005, the explosions and fires at BP's Texas City refinery that killed 15 people and injured 170 [1]. Why were the events that led to the accident not recognized as harbingers? Why were risk reducing steps not taken?

A recent study by the US National Academy of Sciences, which brought together experts on risk, engineers, practitioners, and policy makers from different industries, focused on the signals, conditions, events and sequences that preceded and led up to accidents, and stated that many organizations had attempted to develop programs to identify and benefit from accident precursors [2]. In this book, the author described the precursors strategies in aviation, the chemical industry, health care, nuclear power and security operations. In addition to current practices, they also address some areas for future research.

Using accident precursors to predict and prevent accidents is not a new idea. In the nuclear industry, the U.S. Nuclear Regulatory Commission (NRC) started the Accident Precursors Sequence Program in 1979 [3]. Over 1,000 licensee event reports are submitted to the nuclear power plant (NPP) regulator, the NRC, each year. The Aviation Safety Reporting System operated by the National Aeronautics and Space Administration, have been in existence for several decades. The offshore petroleum industry in Norway has also reported major hazard precursors to the authorities for a decade [4]. Renewed interest in precursors analysis has shown that the evaluation of near misses is an interdisciplinary effort, fundamental within the life of an organization for reducing operational risks and enabling accident prevention [5]. There has been notable work in the codifying and evaluation of precursors data through utilization of Bayesian analysis [6][10]. Pate-Cornell presents a probabilistic approach to use precursors analysis to create "signals that action has to be taken ... to reduce the risks of failure as much as possible within resource constraints [11]." Carroll demonstrates the importance of knowledge management within organizations, so that precursors can be effectively addressed as "signals of possible problems" and "opportunities to enact and improve organizational practices [12]." Phimister et al. not only observe the interdisciplinary nature of precursors analysis but also the fact that this practice is diffused across different industries [2].

Near misses are well known for providing a major source of useful information for safety management. The use of data from near misses in safety management has been identified as an important practice in the prevention of accidents, especially in the areas of civil aviation, the generation of nuclear power, the chemical industry and, more recently, in railroad transport and medicine [13].

Near misses management systems have been developed and are implemented across a range of industries, including the chemical and process, airline, rail, nuclear, and medical disciplines [10]. A compilation of papers with a cross industry perspective is provided in Near misses Reporting as a Safety Tool [14]. The most detailed study of near misses management in the chemical industry known to us is the thesis of Van der Schaaf [15]. Jones et al. provide an account of near misses management systems successfully applied in the European chemical industries [16].

Some studies have investigated how data from near misses should be used in safety management. However, each study tends to emphasize one of the following steps: identifying near misses, analyzing data and defining actions resulting from the investigation of the events [17]. For example, Brazier, Reason, Van Der Schaaf and Kanse, Renshaw and Wiggins, Dekker focused on the stage of identifying these events [13], [18][21]. Bier and Mosleh addressed the analysis of near misses [7]. The study by Van Der Schaaf, undertaken in the context of the chemical industry, proposed a set of steps for the use of data from near misses [22].

This research focuses on differentiating the concepts of precursors related and evaluating the risk of precursors, near misses. The first part of the paper briefly reviews some of the previous studies. The remainder of the article is organized as follows. In Section 2, the definitions of concepts precursors related are presented. Section 3, differentiate the concepts precursors related. Section 4, describes the importance of precursors and near misses to further improve safety margins. Section 5, risk-based evaluation of precursors and near misses is proposed. Section 6, emphasized the impact of precursors and near misses on quantitative risk estimates. Section 7, provides conclusions.

II. Review of precursors and near misses related concepts

A. Precursors

Recognizing signals before an accident occurs

offers the potential for improving safety, Many organizations had sought to develop programs to identify and benefit from accident precursors, A recent study by the US National Academy of Sciences focused on these precursors which were defined as the conditions, events and sequences that preceded and led up to accidents or the 'building blocks' of accidents [2]. The National Academy of Engineering workshop definition of an accident precursor is any event or group of events that must occur for an accident to occur in a given scenario, Based on this definition a precursor is identified in a much wider range of severities and may include all defects and abnormal events. Similarly, Suraji et al. explained this concept as an undesired event, which was an unwanted incident immediately preceding and leading to an accident that did, or could have caused injury to construction personnel or the general public, or damage to property or the environment [23]. Skogdalen and Vinnem described a precursor incident is an event or group of events that indicates failure in systems controlling the risks from a major hazard [24]. When adopting a broad definition of precursors, it is not difficult to find that a near miss accident is an important kind of precursors [2], [19]. However, some organizations such as the U.S. NRC, have chosen to limit the use of the term 'precursors' to events that exceed a specified level of severity. For example, precursors might be defined as the complete failure of one or more safety systems and/or the partial failure of two or more safety systems [2]. Likewise, Wu et al. adopted the concept of precursors to the events that exceed a specified level of severity [25].

B. Near misses

To organizations seeking to learn about potential accidents, near misses represent inexpensive learning opportunities for analyzing what can go wrong. Near misses are especially important for organizations that have not experienced a major accident, because they enable these organizations to experience what March et al. refer to as "small histories"—or fragments of what might be experienced if an accident occurred [26]. To benefit from near misses, organizations ranging from hospitals to manufacturing facilities and airlines to power plants, have set up management systems for reporting and analyzing near misses [7], [15], [16], [27].

It has been widely accepted that accidents are just the tip of an iceberg. Near accidents, events in which no damages or injuries occur but, under slightly different circumstances, could have resulted in harm, are important sources of information about accident precursors [28], [29]. Near misses accidents were usually referred to as precursors of accidents [7], indicators of potential accidents when luck runs out [30] or imminent signals of accidents [16]. Ritwik adopted a very simple definition of near misses as an incident or unsafe condition with potential for injury or property damage [31]. Phimister et al. defined near misses as an opportunity to improve environmental, health and safety practice based on a condition, or an incident with potential for more serious consequence [10]. Phimister et al. identified a near miss accident as a special kind of precursors and it was defined as an event in which no damages or injuries actually occurred but, under slightly different circumstances, could have resulted in harm [2]. In construction, the modified statistical triangle of accident causation described the same process from near miss accidents to fatal accidents [32]. Cambraia et al. adopted the concept of a near miss accident as an instantaneous event that involved the sudden release of energy and had the potential to generate an accident [17]. Its consequences do not result in personal injuries or material damage, but usually only in the loss of time. This concept also implies that a near miss has the potential to result in accidents with exclusively material damages. Rathnayaka et al. describes the term 'near miss' as an event that does not result in an actual loss but that has the potential to do so [33].

C. Immediate factor

Undoubtedly, immediate factors are important exacerbating factors of accidents. An updated domino sequence led to the comprehension of immediate causes before an accident [34]. Jones et al. defined the direct causes as immediate reason why an incident occurred, usually consisting of unsafe conditions at the site or unsafe acts by a person [16]. Chua et al. described the immediate causes are the triggers that directly lead to the incident sequence, Further he classified the immediate causes into substandard/unsafe conditions and substandard/unsafe acts, which refer to the respective physical conditions and human behaviors that do not meet safety requirements and can directly cause incident occurrences [35]. Fang et al. found that immediate factors were caused by unsafe conditions and unsafe actions [36]. The Loughborough's ConCA accident causality model recognized that immediate accident circumstances were failures in the interaction between the work team, workplace, equipment and materials. Wu et al. adopted the same concept in their research [25].

D. Incident

It is common to use the term near miss as a synonym of incident [19], [37]. However, some authors consider that incidents include accidents, near misses, unsafe acts and conditions [13], [16], [18]. Similarly, Jones et al. defined incidents as all undesired events, including accidents and near misses [16]. Phimister et al. defined incidents as all safety related events, including accidents (with negative outcomes, such as damage and injury), near misses (situations in which accidents could have happened if there had been no timely and effective recovery), and dangerous situations [2]. Cambraia et al. described incidents as an umbrella term adopted to refer to any situation in which there is a lack of safety. There are different points of view in some research [17]. Heinrich et al. defined an incident as an undesired event that could (or does) downgrade the efficiency of the business operation, the concept do not refer to actual injury to a person [38]. Rathnayaka et al. described an incident is an event that could cause considerable harm or loss [33].

E. Accident

Heinrich et al. considered an accident is unplanned and uncontrolled event in which the action or reaction of an object, substance, person, or radiation results in personal injury or the probability thereof [38], Based on this definition accidents could encompass the idea of no injury accidents as well as injury accidents. Bentil described accident as an unplanned act, event or occurrence, within a sequence of events, which can cause unintended personal injury or death, property damage or both [39]. Perrow defined an accident as a failure in a subsystem, or the system as a whole, that damages more than one unit and in doing so disrupts the ongoing or future output of the system [40]. Qureshi described an accident as an event that occurs from inappropriate or inadequate control or enforcement of safety-related constraints on the development, design, and operation of the system, rather than simply occurring due to independent component failures [41]. Rathnayaka et al. identified an accident as an event that may cause fatalities, damage to property and impact to the environment [33]. Simultaneously, accidents were classified according to the degree of severity by some research [16], [32], [33].

F. Harzard

We are surrounded by hazards all our lives. Most of them we accept without concern [42]. Bentil defined hazard is a condition, act or event that has the potential of causing an accident or illness [39]. A hazard is "an inherent physical or chemical characteristic that has the potential for causing harm to people, the environment, or property" [43]. The Health and Safety Commission defined hazard as the potential to cause harm [44]. Hazard has also been defined as an inherent

characteristic of a thing or situation that has the potential of causing an unplanned or undesired event or series of events that have harmful consequences, such as injury, death, environmental harm, or illness [45].

F Safety barrier

The term safety barrier and similar terms like defence (in-depth), layer of protection, safety (critical) function, safety critical element, and safety system are applied in regulations, standards, and the scientific literature [46]. No common definition of the term safety barrier has been found in the literature, although different aspects of the term have been discussed and applied in practice for several decades. Safety barriers are categorized in numerous ways by different authors and the performance of the barriers is described in several ways.

In the Oxford English Dictionary a barrier is defined as a ‘‘fence of material obstruction of any kind erected (or serving) to bar the advance of persons or things, or to prevent access to a place’’ [47]. The concept of defence-in-depth constitutes the basis for the discussion of safety barriers. IAEA describes the term safety barrier is often used in a broader meaning as a collective term for different means used to realize the concept of defence in depth [48]. A safety barrier is related to a hazard, an energy source or an event sequence. This is supported by the requirement stated by PSA [49]. This means that a barrier should be well defined or formalised and be related to a specific hazard. Sklet suggests the definition of safety barriers are physical and/or nonphysical means planned to prevent, control, or mitigate undesired events or accidents [46].

III. Relationships between the aforementioned concepts and differentiate the relevant concepts

In spite of all kinds of safety measures and indicators used, major catastrophes still occur [50]. Were there no signs indicating that an accident was on its way? Heinrich already stated that an accident is preceded by numerous incidents and near misses in his famous iceberg metaphor [51]. Similarly, Investigation of major accidents shows that for every serious accident, a larger number of incidents result in limited impact and an even larger number of incidents result in no loss or damage [10]. Several authors mention the existence of precursors being present in the organization before an accident occurs. For example, Lees and Tweeddale mention only technical precursors [52], [53], whilst Reason, Turner, and Perrow indicate the presence of organizational precursors [19], [54], [55]. Various accident triangles show that for each major accident there are a large number of minor accidents and even more near misses [10], [32], [53].

It has been demonstrated in various studies, e.g. (Bird and Germain, 1966; Tye, 1976; Heinrich, 1980) that there is a relationship between the numbers of near misses, minor incidents and major accidents [38], [56], [57]. In order to effectively discuss, Phimister et al. defined precursors are sequences or events in the accident chain, accidents have been preceded by events, behaviors, and conditions that were ingredients of the recipe for the adverse consequences [2]. On some occasions a precursor event can be considered synonymous with a near miss. Precursors are signals of possible problems, chinks in an operation’s armor, or pathways to accidents. They are called precursors rather than accidents because systems have multiple layers of defense like slices of Swiss cheese stacked together [19]. A precursor problem may pass through one or two layers of defense (through the holes in the Swiss cheese), but another layer usually stops the progression toward an accident. Only when “all of the holes line up” does the problem overcome or bypass all defenses and become an accident.

It should be pointed out that when adopting a broad definition of precursors, it is not difficult to find that near miss is an important kind of precursor [2], [16]. However, some organizations,

such as the U.S. NRC, have chosen to limit the use of the term precursors to near misses that exceed a specified level of severity [2]. Likewise Wu et al. adopted the same concept. Although near misses are clearly related to precursors [25], Phimister et al. have tried to distinguish near misses from precursors, and encourage not to use them interchangeably [2]. They define a near miss is as an almost complete progression of events—a progression that, if one other event had occurred, would have resulted in an accident. A near miss might consist of one or more precursors that did occur, and one that did not. Based on this definition, a near miss can be considered a particularly severe precursor. For instance, when the necessary exacerbating factors are highly likely, the precursor is called a near miss. Similarly, one would expect a precursor to be called a near miss if the mitigating factors were unlikely or not robust. Likewise Meel and Seider described the near misses and incidents are also called accident precursors as their occurrences portend an increasing likelihood of accidents, near misses have less potential for adverse scenarios compared with incidents, but when recognized, they signal the likelihood of future incidents and accidents, often in time to take preventive action [58]. By reviewing previous research, the relationship between the numbers of precursors, near misses, minor incidents and major accidents could be described by the well known Safety Pyramid [56] shown in Fig. 1.

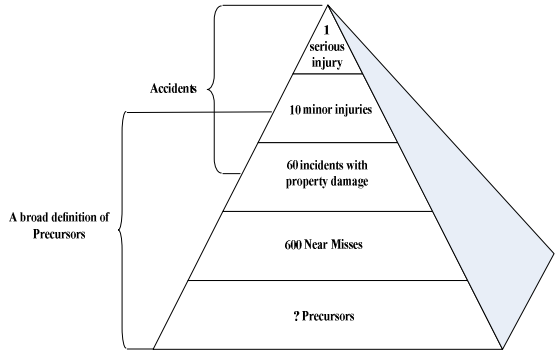

Fig. 1. Safety pyramid (the lowest strata, precursors, is not shown by Bird and Germain, 1966)

It is also common for no distinction to be made between the terms near misses, unsafe acts and conditions. Cambraia et al. considered that the difference between these events is in the time of the action and in whether or not there has been a sudden release of energy [17]. While in unsafe acts and conditions, the situation of risk arises from a continuous action or is latent in the environment (for example, an employee working high up who does not use a safety belt), in near misses there is an instantaneous action, which involves the sudden release of energy.

Immediate factors are important exacerbating factors of accidents on construction sites. An updated domino sequence led to the comprehension of immediate cause before an accident [34]. Differences between precursors and immediate factors lie in the difficulty for performing preventive actions due to time constraint. Immediate factors always have tight period allowed for taking actions [25].

In this study, the general definition of precursors, near misses, immediate factors, incident, accident, hazard and safety barriers have been used [2], [16], [45], [46]:

The precursors are defined as sequences or events in the accident chain, a precursor problem may pass through one or two layers of defense (through the holes in the Swiss cheese), but another layer usually stops the progression toward an accident. A near miss is defined as an almost complete progression of events—a progression that, if one other event had occurred, would have resulted in an accident. Immediate factors are defined as immediate causes before an accident. Incidents are defined as all safety related events, including accidents, near misses and precursors. A accident is defined as an complete progression of events (all of the holes in the Swiss cheese line up). A hazard is defined as an inherent characteristic of a thing or situation that has the potential of causing an unplanned or undesired event or series of events that have harmful consequences, such as injury, death, environmental harm, or illness (holes in the Swiss cheese). Safety barriers are defined as

physical and/or non-physical means planned to prevent, control, or mitigate undesired events or accidents.

According to the above definitions, the presented paper described the relationships of the above concepts by a causal sequence diagram (Fig. 2).

Based on the Safety pyramid (Fig.1) and the causal sequence diagram (Fig.2), this paper differentiate the precursors, near misses and accidents from three aspects of proximity, incidents rates, potential consequence by a bubble chart (Fig.3).

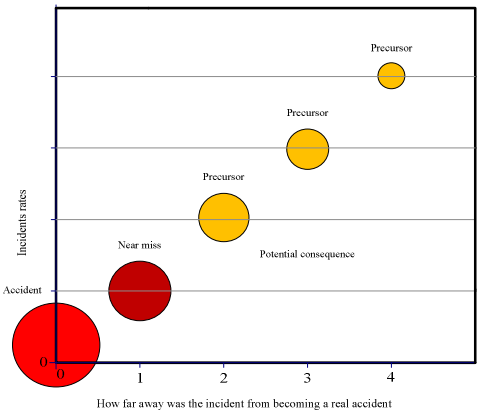

Fig.3. Bubble chart

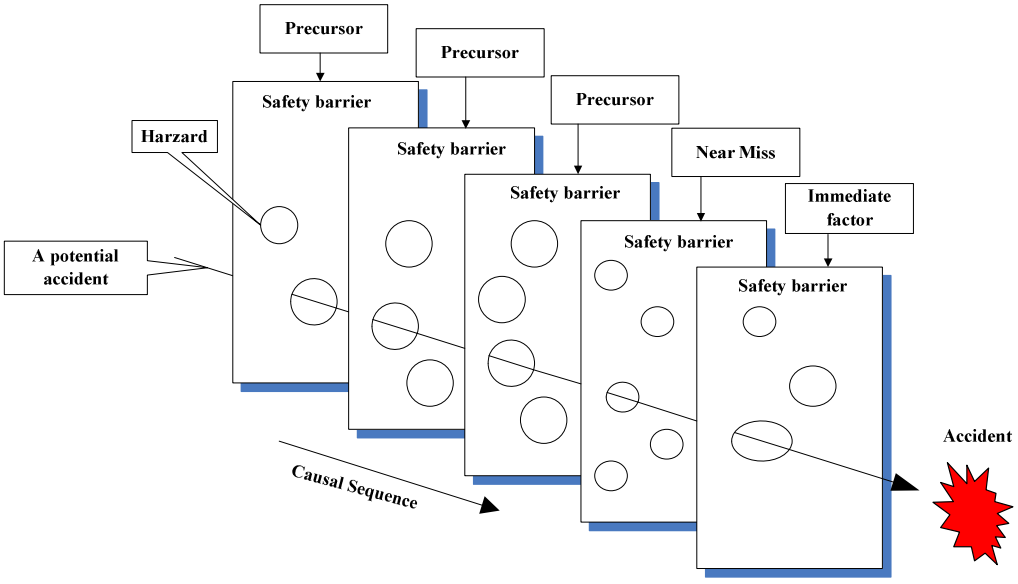

Fig. 2. Causal sequence diagram of the accident

IV. The importance of precursors and near misses to further improve safety margins

A primary purpose in measuring safety is to develop intervention strategies to avoid future accidents [59]. Recognizing signals before an accident occurs offers the potential for improving safety, and many organizations have sought to develop programs to identify and benefit from alerts, signals and prior indicators. A recent study by the US National Academy of Sciences focused on these signals, the conditions, events and sequences that precede and lead up to accidents, or the ‘‘building blocks’’ of accidents [2]. Grabowski et al. also echoed that recognizing alerts and signals before an accident clearly offers the potential of improving safety [59].

In the aftermath of catastrophes, it is common to find prior indicators, missed signals, and dismissed alerts that, had they been recognized and appropriately managed before the event, might have averted the undesired event [2]. To prevent major, though infrequent, event occurrence, it is important to consider accident precursors (symptoms of hazards) such as operational deviations,

mishaps, and near misses, in order to prevent events at source rather than controlling or mitigating them [33]. One of the most attractive aspects of precursors analysis is the abundance of precursors events compared to actual accidents [56]. Analyzing precursors data can therefore reduce the uncertainty about the likelihood of an accident and lead to better decisions. The relatively high frequency and low cost associated with precursor events suggest that many industries could benefit from using precursors analyses to reduce the risk of accidents.

Programs for managing accident precursors have a number of benefits, as outlined by van der Schaaf et al. [14]. First, reviewing and analyzing observed precursors can reveal what can go wrong with a particular system or technology and how accidents can develop (modeling). Second, because precursors generally occur much more often than accidents, analyses of accident precursors can help in trending the safety of a system (monitoring). Finally, and perhaps most important, precursors programs can improve organizational awareness (mindfulness) of safety problems [60]. The investigation of precursor events can be used as a source of information for the construction of a structured methodological approach for operational decisions [61]. Skogdalen and Vinnem thought that information from precursor incidents investigations can also be important tools for improved risk communication [24].

One way organizations seek to benefit from precursors is by analyzing near misses (sometimes referred to as near accidents, near hits, or close calls), fragments of an accident scenario that can be observed in isolation—without the occurrence of an accident [10]. Precursors analysis, the evaluation of "near misses," has been an activity of the U.S. Nuclear Regulatory Commission (NRC) for almost twenty years [24]. For a given accident scenario, near misses can and frequently do occur with greater frequency than the actual event [56]. Similarly, the "Iceberg concept" about the proportionality between different categories of accidents and near misses also says that the more near misses (or other deviations) you have the more frequently you will have accidents.

To organizations seeking to learn about potential accidents, near misses represent inexpensive learning opportunities for analyzing what can go wrong. Near misses are especially important for organizations that have not experienced a major accident, because they enable these organizations to experience what March et al. refer to as "small histories"—or fragments of what might be experienced if an accident occurred [26]. To benefit from near misses, organizations ranging from hospitals to manufacturing facilities and airlines to power plants, have set up management systems for reporting and analyzing near misses [7], [15], [16], [27].

As near misses are much more frequent events that accidents, they may indicate, in a proactive way, critical areas for improvement in safety management [16], [19], [22], [37]. In addition, using near misses helps to strengthen the safety culture [16], [62], [63], especially when workers are motivated to participate in the process of identification and analysis of those events [16], [19]. Indeed, studies in the construction and chemical industries have indicated that accident rates tend to diminish in keeping with the rate at which the number of near misses identified increases [16], [64]. So if we report near misses, and learn from them, we will eventually get to the point where near misses occurrence itself reduces. A reduction in the numbers of near misses which proceed to full-blown accidents follows.

V. Risk-based evaluation

In this passage, a decision matrix risk assessment technique is presented, which has been based on and produced with the help of the works of Johnson, Woodruff, Reniers et al., Marhavilas and Koulouriotis [65][68].

The combination of a relevance index and consequence potential factor range, gives us an estimate of risk (or a risk ranking). The relevance index is composed of proximity index (1), visibility index (2) and Probability index (3). The consequence potential factor is composed of casualties (a), property Loss (b), environmental releases/exceeding standards (c) and evacuation (d).

Furthermore, the product of the relevance index and consequence potential factor provides a measure of risk which is expressed by the relation:

Relevance index=1+2+3

Consequence potential factor=a×b×c×d

In order to reduce the subjectivity of the evaluation, criteria were established to classify precursors or near misses according to their degree of severity (level of impact if the accident had happened), proximity (how far away was the incident from becoming a accident),visibility (is the incident visible before it lead to the accident) and probability (estimate of the likelihood of an accident occurring if no preventive action additional to those already in place is taken), as shown in Tables Ⅰ and Ⅱ. Criteria and their weightings could be customized to suit local needs.

Once the precursors or near misses has been identified, the question of assigning relevance index and consequence potential factor must be addressed, like in Tables 1 and 2. It is very important to note that frequency estimations and consequence estimations are very well considered and performed by experienced risk managers [67].

Eventually, the technique is consummated by the construction of the risk matrix (in Fig.

Table I

Data for relevance index

Relevance index	
Criteria	Weighting
1.Proximity index	
How far away was the incident from becoming a accident?	
One step away	3
Two steps away	2
More than two steps away	1
Remote	0
2.Visibility index	
Is the incident visible before it lead to the accident?	
With great difficulty	3
Some insight	2
Obvious	1
Widely know	0
3. Probability index	
Occurrence rate of the incident in daily operation.	
High probability	3
Medium probability	2
Low probability	1
Not expected to happen	0
Relevance index (1+2+3)	0 to 9

Table II

Data for consequence potential factor

Consequence potential factor	Weighting
a) Casualties	
Death	3
Serious injury	2
Injury	1
b) Property Loss	
$500,000 or more	3
$50,000-500,000	2
$0-50,000	1
c) Environmental releases/ Exceeding standards	
8 hours or 100%	3
1 hour or 10%	2
30 minutes or 5%	1
d) Evacuation	
More than 100 individuals	3
50-100 individuals	2
Less than 50 individuals	1
Consequence potential factor (a×b×c×d)	0 to 81

4), which have been developed by the combination of Tables □ and □ and the usage of the above relation.

The developed decision matrix risk assessment technique has two key advantages: a) It differentiates relative risks to facilitate decision making. b) It improves the consistency and basis of decision. Moreover, it is a quantitative (due to risk measuring) and also a graphical method which can create liability issues and help the risk managers to prioritize and manage key risks.

The relevance index and consequence potential factor associated with each precursor or near miss will be the basis to classify the incident in one out of three zones of risk (Fig. 4): red (incidents with the highest risk), yellow (incidents with medium risk) and green (incidents with the lowest risk). The red zone means that not enough barriers have been implemented and risk cannot be tolerated. The yellow and green zones finally state that enough layers of protection are present in order not to select the scenario. The classification in zones is necessary since the choice was made not to assign weights to rank each category of relevance index and severity.

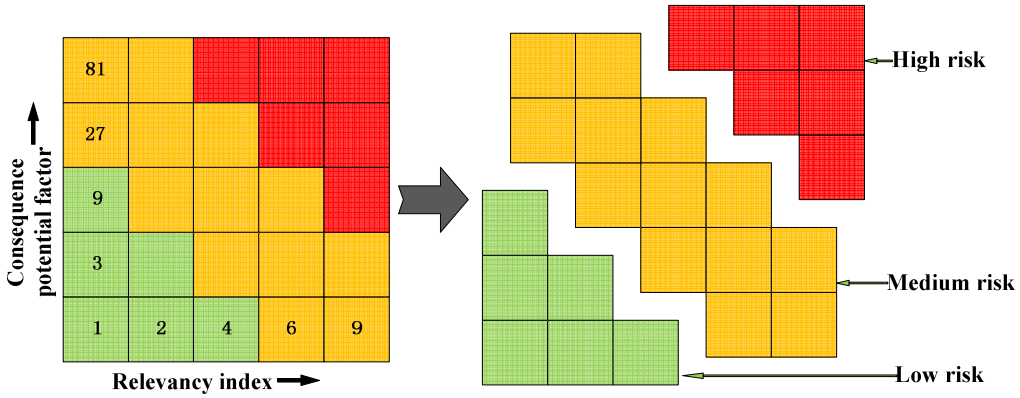

Fig. 4. Risk matrix of precursors and near misses

VI. Impacts on quantitative risk estimates

In estimating the frequency of rare events, the number of observed events (typically either 0 or 1) will generally be too small to support the development of accurate estimates by means of the usual statistical estimator, Two alternative approaches have been suggested to overcome this problem: (1) probabilistic risk analysis (PRA), in which the accident frequency is estimated as a function of the failure rates of individual components; and (2) the use of data on accident "precursors" or "near misses" [6]. Kirchsteiger thought that the significance of quantitative risk estimates depends not only on the number of accident events included, but also on the criteria differentiating accidents and accident precursors [9].

Since precursors (near misses) consist of event sequences rather than individual component failures, precursors data will automatically reflect the effects of any dependencies that may exist between components or systems that were challenged during the observed precursors [6]. The analysis of precursors data has therefore attracted considerable attention as an approach for estimating the frequencies of severe accidents.

As it is well known, the occurrence rate Φ of an accident of a certain type with consequences equalling or exceeding a certain magnitude can be quantified as a maximum-likelihood estimate across the given observation time T,

$$\Phi|_{T=}\frac{\text{No.of accidents}}{\text{observation time T}}.$$

Taking into account precursors or near misses, the frequency of an accident can be represented as the product of two quantities,

$$\Phi|_{T=}\sum_K \lambda_k \varphi_k$$

where, $\Phi|_T$ = frequency of a specific accident in observation time T (e.g. fire in a plant with fatalities or injuries > 0), λ_k = frequency of precursors or near misses type k (e.g. any fire in the plant), φ_k = conditional frequency of the accident of interest, given a precursors or near misses of type k (e.g. fire with fatalities or injuries > 0, given any fire) [16].

Based on the above discussion, Jones et al. described near misses can thus be viewed to yield either an increased or a decreased overall accident frequency by either increasing the near misses frequency or decreasing the conditional frequency of an accident given a near misses, depending on the prior distributions for both the near misses frequency and the conditional accident frequency [16].

The question of interest is thus whether the inclusion of observations of precursor and near miss events which do not end up in accidents can actually result in significantly different (increased or decreased) accident frequencies and thus overall risk estimates. As analytically shown in Kirchsteiger [9], the inclusion of near misses events not resulting in an accident has the potential to significantly increase the values of corresponding risk estimates. In other words, not considering precursors and near misses occurrences can result in significant under estimation of the "true" risk.

Thus, if the statistical basis for quantitative risk estimates consists only of "top events" (e.g. accidents of a certain type) instead of explicitly covering both accidents and accident precursors, there is the danger that—since the number of near misses (i.e. of precursors to the specific accident type under consideration) is often quite large compared to the number of accidents—"conventional" risk estimates of the

$$\Phi|_{T=}\frac{\text{No.of accidents}}{\text{observation time T}}.$$

type are not very dependable.

VII. Conclusions

The concepts of precursors, near misses are presented and discussed in the paper. The results are based on experience from several research projects focusing on precursors, near misses and a review of relevant literature. No common terminology applicable crosswise between sectors and application areas has been found, and a set of definitions is therefore proposed in the paper.

Precursors are defined as sequences or events in the accident chain, a precursor problem may pass through one or two layers of defense (through the holes in the Swiss cheese), but another layer usually stops the progression toward an accident. While near miss is defined as an almost complete progression of events—a progression that, if one other event had occurred, would have resulted in an accident. Accident is defined as a complete progression of events (all of the holes in the Swiss cheese line up). So defined in order to facilitate the distinction between precursors, near misses and accidents.

It has been demonstrated in various studies, e.g. (Bird and Germain, 1966; Tye, 1976; Heinrich, 1980) [38], [56], [57] that there is a relationship between the numbers of precursors, near misses, minor incidents and major accidents. Investigation of major accidents shows that for every serious accident, a larger number of near misses and an even larger number of precursors. In this paper, the author described the relationship between precursors, near misses and accidents by a Safety pyramid, Causal sequence diagram of the accident and a

Bubble chart.

The importance of precursors and near misses to further improve safety margins has been emphasized. Analyzing precursors data can therefore reduce the uncertainty about the likelihood of an accident and lead to better decisions. The relatively high frequency and low cost associated with precursors events suggest that many industries could benefit from using precursors analyses to reduce the risk of accidents.

To organizations seeking to learn about potential accidents, near misses represent inexpensive learning opportunities for analyzing what can go wrong. Near misses are especially important for organizations that have not experienced a major accident, because they enable these organizations to experience what March et al. [26] refer to as "small histories"—or fragments of what might be experienced if an accident occurred.

In this paper, a decision matrix risk assessment technique is presented. The combination of a relevance index and consequence potential factor range, gives us an estimate of risk (or a risk ranking). The developed decision matrix risk assessment technique is a quantitative (due to risk measuring) and also a graphical method which can create liability issues and help the risk managers to prioritize and manage key risks.

The impact of precursors and near misses on quantitative risk estimates has also been emphasized. If the statistical basis for quantitative risk estimates consists only of "top events" (e.g. accidents of a certain type) instead of explicitly covering both accidents and accident precursors, there is the danger that—since the number of near misses (i.e. of precursors to the specific accident type under consideration) is often quite large compared to the number of accidents—"conventional" risk estimates are not very dependable.

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