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Measuring the effectiveness of a near-miss management system: An application in an automotive firm supplier

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ABSTRACT

Accidents and near-miss events are usually characterized by common causes and different consequences; a near-miss event is a potential hazardous condition where the accident sequence was interrupted; these events have common causes with accidents (or injuries), but, differently from the latters near miss consequences are null (or reduced).

Thus, near-miss events are accident precursors; furthermore, they provide “weak signals” to safety managers for preventing more effectively injuries at workplace. The study proposes a methodological framework to verify the global effectiveness of a near-miss management system (NMS): the model is based on lean safety and learning loops strategies. The proposed framework uses data collected by the firm NMS crossed with information extracted from occurred accidents/injuries. A case study in an automotive firm supplier is proposed aiming to validate the proposed framework. The analysis has revealed effective to outline overall potentialities of the proposed approach together with improvement points for the firm NMS application.

1. Introduction

Near miss events differ from accidents (or injuries) as the accident chain has been interrupted by such a condition: on the other hand, near miss events and accidents are usually based on common causes. Near miss events are defined as a hazardous situation where the event sequence could lead to an accident if it had not been interrupted by a planned intervention or by a random event [14,25,20,24,29]. Thus, near miss events are also defined as accident precursors as they outline potential causes leading to an accident before a real accident happens. Past and recent studies have outlined the importance of analyzing accident precursor events even if their analysis requires a higher effort than accidents and/or injuries [13,1,33,17] as their number is usually higher than one due to real accidents. On the other hand, analyzing accident precursors could provide the development of more effective prevention strategies, as accidents and precursor events are usually characterized by common causes: thus, it allows to identify deficiencies before accidents occur. Accident precursors represent a relevant source of knowledge for increasing safety levels in an organization as they point out lacks in safety system – the so called “weak signals” – without causing high consequences [19,21,23,8,34]. Monitoring “weak signals” and analyzing their causes will lead to prevent accidents in a more effective way.

The near-miss management system (NMS) developed by a company is the organizational tool for reporting and analyzing accident precursor in a firm in order to outline effective prevention programs for increasing its occupational safety levels [18,9]. NMSs have been also introduced in the OHSAS 18001 standard ([2]) as a relevant tool for the firm safety management system.

Although measuring performance of the safety management system is not a new issue, measuring the effectiveness of a NMS is relatively new. Few recent studies [15,6] have proposed a cross analysis between injuries and near-misses in a high risk sector (the oil industry) based on data derived from large databases; a structured approach for analyzing data derived directly from the field (e.g. a specific firm) has not been yet suggested. The aim of this study is to propose and validate a general framework for measuring the effectiveness of a NMS. Based on a proactive approach, the starting point will be the main features usually characterizing near-miss events such as the knowledge provided for preventing accidents. Thus, the proposed model will use a cross analysis between accident precursors and injuries recorded at a workplace to provide information for monitoring the effectiveness of a NMS. A case study about an automotive firm supplier applying lean safety strategies is discussed. The paper has been organized as follows: the general framework for measuring performance of a NMS system is described in detail in Section 2;

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a case study is analyzed in Section 3 in order to validate the proposed approach, and results obtained are finally discussed.

2. Measuring effectiveness of a near miss management system in a manufacturing firm

NMSs are widespread since several years in industrial contexts characterized by high risk levels, such as chemical and petrochemical sectors [30,27,16]: few recent applications are developing in other industrial sectors – such as the manufacturing [10] – where the NMS design and application have to be integrated with different approaches, such as lean safety. According to lean thinking approaches, greater importance is assigned to the performance measurement process to outline improvement points in such a field of analysis; thus, lean safety approaches are mainly focused on learning by experience models. In brief, the lean safety approach – which is derived from the more wide strategy of lean thinking – is based on the well-known Deming continuous improvement cycle, i.e. the plan-do-check-act cycle. Furthermore, the "personal responsibility" concept is emphasized in lean safety approaches than in traditional ones: each employee contributes according to its own competence to improve performance; employers at all firm levels are directly involved to apply continuous improvement process as it is the most important fiat target. This strategy forced the application of an innovative safety culture and tools where workers are involved directly in monitoring and improving safety levels at workplace by a bottom up approach. Thus, lean safety approaches aim to minimize occupational risks, by boosting firm performances through continuous learning from the past experiences as well as effective benchmarking processes [11]. Applying a continuous improvement approach to safety management allows to develop proactive programs, rather than just to be compliance to such legislative requirement.

NMSs represent effective tools for applying lean safety approaches in a firm as they provide both employer engagement in improving safety levels and an updated "knowledge" from the operational field about actual safety levels at workplace. On the other hand, designing and managing NMS according to a lean safety approach requires new approaches [9].

By adopting the Deming cycle for designing and managing a NMS in a firm, four main steps could be outlined as depicted in Fig. 1: the first two refer to the NMS design and its application based on specific features regarding the industrial sector; next, the check phase has to be developed in order to evaluate if a following re-design action or a continuous improvement policy has to be applied. This model allows to design and manage NMSs based on learning loops, which are pillars of an effective safety management systems.

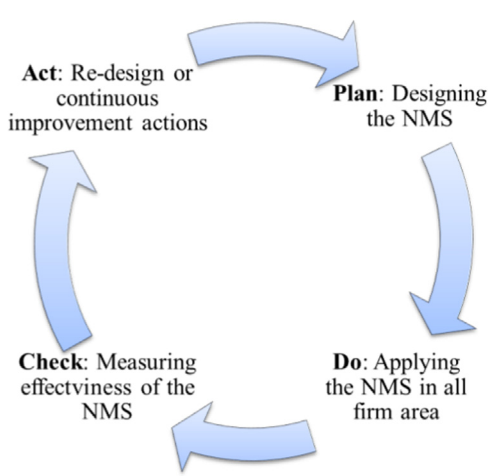

Fig. 1. The Deming cycle applied for NMSs.

Thus, the focus of the proposed study is to evaluate a reference framework for measuring the actual effectiveness of a NMS as an important source for preventing occupational accidents at workplace.

Based on common issues characterizing the near-miss literature, two main questions could be outlined as "performance indicators" of the NMS effectiveness:

Question 1. *Is the NMS reporting process quantitatively effective*?

Several consolidated studies – starting from the well-known Heinrich pyramid [13] to most recent ones [4,17] – outline that the total number of reported accident precursor events are usually higher than the total number of observed injuries. Thus, a first quantitative "metric" for measuring how workers are involved in the reporting process could be a comparison between the total number of events reported versus the occurred number of injuries/accidents in a specific time window.

Question 2. *Is the NMS reporting process qualitatively effective?*

Accident precursors are weak signals providing knowledge for preventing injury or damage; they are often characterized by common causes [19,18,21,33,23,22]. Furthermore, similarly to the root cause analysis carried out for accidents/injuries occurred at workplace [12,26,5], analyzing accident precursor events could contribute to increase the "Learning From Experience" approach of the firm. Thus, investigating if such a common causal factor could be outlined between precursor and injury events is a way for "measuring" the efficacy characterizing the reporting process. Furthermore, this analysis of precursor events will provide updated information about most widespread risk sources outlined directly by employers: this knowledge will allow the safety managers to address more effective interventions in their own safety management system.

Based on these issues, a framework for analyzing performance of a NMS is depicted in Fig. 2.

The process starts from outlining each single firm area, which could be equal to the shop floor organization.

Next, the main purpose is to verify the distribution of both precursor and injury/accident events in each plant area. Two indexes, defined as Precursor and Accident Index, have been introduced aiming to normalize the number of events according to the actual number of workers in each department. The Precursor Index (PI) for the ith department is defined in Eq. (1)

$$\text{Precursor Index}_i = \left(\frac{\text{NM}+\text{UA}+\text{UC}}{N_{\text{EMP}}}\right)_i \quad i = 1, \ldots, 10 \tag{1}$$

where NM, UA, and UC are the total number reported of near-miss events, unsafe acts and conditions, respectively; the N_{EMP} represents the total number of workers.

The Accident Index (AI) for the kth department is defined in the following equation:

$$\text{Accident Index}_i = \left(\frac{\text{IN}}{N_{\text{EMP}}}\right)_i \quad i = 1, \ldots, 10 \tag{2}$$

where IN is the total reported number of injuries occurred in the ith department in the time period. Based on firm internal procedures, IN could be evaluated by adding only the total number of hospitalized injuries or, otherwise, also non-hospitalized injuries could be added in the factor evaluation.

After index estimation for each plant area, a quantitative comparison between AI and PI values will be carried out: if the PI value is greater than AI, a first positive feedback about the NMS reporting process could be outlined as obtained results (expressed in terms of

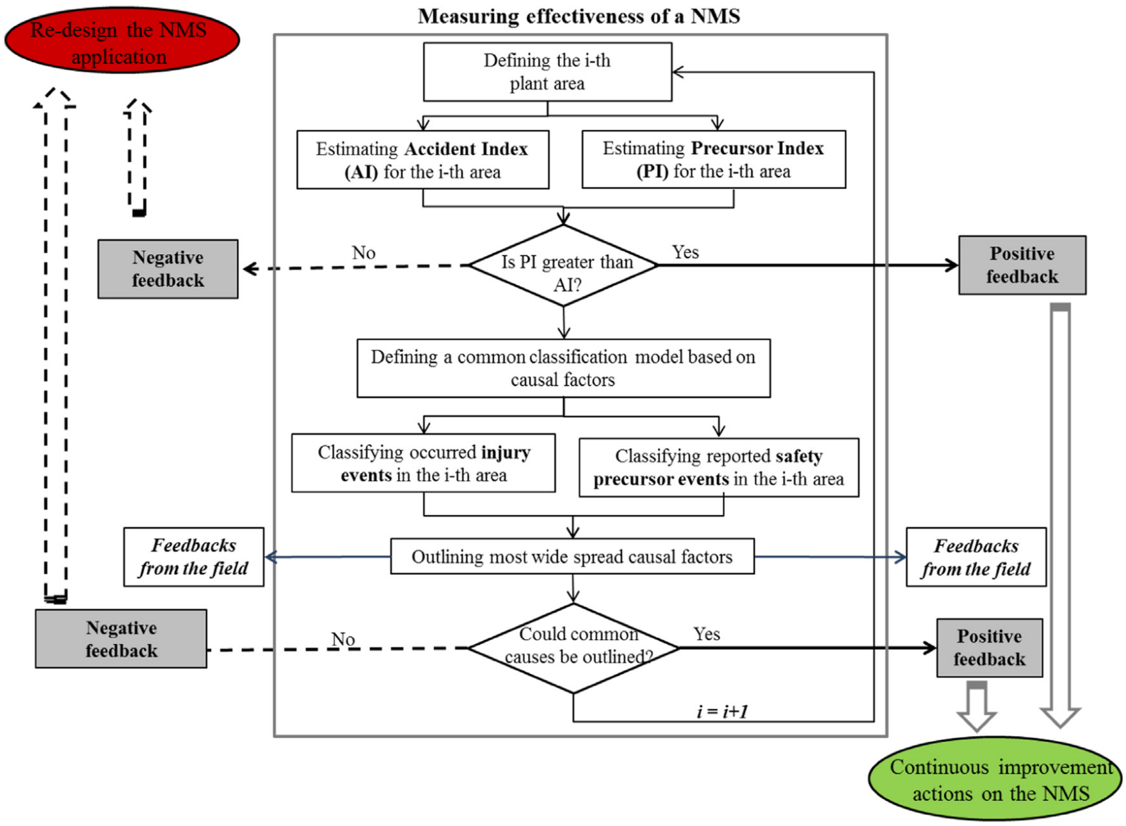

Fig. 2. The proposed framework for measuring effectiveness of a NMS.

number of reported events) are "in line" with the target objectives. Otherwise, negative feedbacks are outlined and a re-design activity involving different actions is necessary for the NMS.

Next, the "quality" of the reported events has to be checked: reported and occurred events will be analyzed according to a common classification model to outline main causal factors leading to specific event occurrence. The classification scheme could be derived from well-established methods applied for accident/injury analysis or it could be derived from the specific risk analysis carried out directly by the firm. By crossing data about reported precursor events and occurred accidents/injuries in a specific plant area, positive or negative feedbacks about the actual state of the NMS could be outlined.

3. The case study

The firm in analysis is the Bosch Bari Plant which produces equipment for the automotive supply chain. It is one of Bosch's largest production sites in Europe and it is the most important Bosch factory in Italy as it produces components for the whole European automotive market. Main products supplied are braking system and high pressure pumps for diesel engines. The total number of workers is about 2200 which are distributed over ten production and administrative departments. Their main features are described as follows:

- Department 1, TEF: it carries out facility management (from equipment verification to maintenance activities); the total number of employees is about 170.
- Department 2, LOG: it carries out logistic (e.g. product material handling) and warehouse activities with 166 employees.
- Department 3, BRK: it carries out all manufacturing activities for producing braking equipment by manual as well as automatic processes. The total number is 261 employees.
- Department 4, SPL: this department supports all firm area production planning and order purchase; the total number of employees is 75.
- Department 5, QAL: it carries out quality controls in the firm; the total number of employees is 100.
- Department 6, ASS: it carries out final assembly processes for diesel pumps: the total number of workers is 542.
- Department 7, FPRO: this production department carries out all manufacturing activities for producing main components of diesel pumps, which will be assembled in the previous department; the total number of employees is 321.
- Department 8, CPRO: it's composed of 256 employees and it manufactures high pressure pump components (e.g. the board, rings, etc.).
- Department 9, BPS: this is a staff department as it supports the application of the Bosch Production System in all plant areas from production processes to administrative management. The total number of employees is 10.
- Department 10, IT: this is the firm service IT department organized with 17 employees.

The firm applies an organizational model based on lean management approach, which is called the Bosch Production System: it is an evolution of the original Toyota Production Systems as new concepts concerning safety and environmental protection have been introduced. In 2011, the firm started to design an innovative NMS which aims to integrate traditional features of NMSs with lean safety approaches. The NMS is based on three types of accident precursor events: *Unsafe Acts*, *Unsafe Conditions* and *Near-Miss Event* [27,3,10,31]. Unsafe acts involve directly a specific human action: it is an action – such as a procedure, a task or an activity – with the potentiality to cause damages at workplace. For instance, a worker driving a forklift with an excessive speed or standing up. An Unsafe Condition is a state characterizing an item, an equipment, a working tool, etc., which could cause property damages or personal injury: one example is a fault in an emergency button or the presence of oil at the ground floor. It affects the overall safety level characterizing a working area by involving indirectly human actions. Finally, a Near-Miss is any event, characterized by the intrinsic high potentiality to cause injury or damage, however, an accidental chain of events or an intervention has reduced its consequences. It represents the most dangerous precursor event as it is very close to an accident or an injury. An example is that an employee slips down the stairs, but, fortunately, he clungs to the railing. In brief, unsafe acts and conditions are characterized by a "probability of hazard" as they outline a potential risk which could determine consequences; near miss events are yet occurred hazardous conditions which have caused a very low (or null) consequence. Thus, Near miss events differs from accidents as they did not causes any consequences; unsafe conditions and acts differ also from accidents as they are the potentiality to cause damage but they do not have yet caused nothing.

The NMS has been fully applied in the Bosch Bari Plant since January 2012: after one year of application, firm management decided to check the effectiveness of its own NMS; thus, annual data about precursors events and injuries have been collected and analyzed according to the proposed framework. Based on firm procedures, all type of injuries (i.e. hospitalized and non-hospitalized) have been recorded by the safety management team.

4. An application of the proposed framework in an automotive firm supplier

4.1. Measuring the efficacy of the reporting process in the NMS

One year data (2012) reported precursor events and injuries have been analyzed. The total number of reported events is 159, that is 6 Unsafe Acts, 123 Unsafe Situations and 30 Near-misses; the total number of occurred injuries is 20. The monthly distribution is in Fig. 3.

Based on these data, PI and AI values have been estimated for each plant department: obtained results are in Fig. 4.

By comparing AI and PI values, several important results can be outlined. First of all, the PI is less than AI in three departments (3, 6 and 7) over ten: these three areas are the large production departments in the firm. The most critical plant area is the Department 7: this is outlined from the inefficiency of the NMS reporting system, and, it is confirmed by the highest AI index value (21.8), which is greater than the one estimated for Department 6 even if the number of workers is greater in Department 6 than in 7 (542 versus 321). On the other hand, the expected trend (i.e. PI values higher than AI ones)

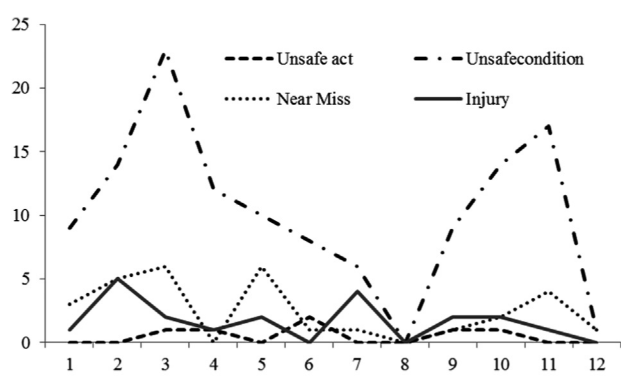

Fig. 3. The monthly distribution of precursor events and occurred injuries in 2012.

is confirmed in Department 8 and 2, which are also characterized by high potential hazards as the previous ones.

By focusing only on data about precursor events, the Department 9 is characterized by the highest PI value: this value is mainly due to the high level of expertise characterizing its employees as it supports the firm management in applying lean thinking and continuous improvement projects: thus, its staff has a greater propensity to signal process non-conformities also in the occupational safety field.

These preliminary aggregated results confirmed that current NMS is not applied effectively in all firm areas: this is mainly outlined by the lower tendency of workers to contribute in reporting precursor events thus helping to reduce the global effectiveness of the NMS in order to prevent accidents and injuries at workplace.

4.2. Measuring the "quality" of the reporting process in the NMS

After the quantitative distribution analysis, a deeper analysis has to be carried out on causal factors contributing to both accident precursors and injuries. As defined in the previous section, the aim is to outline any relationship between precursors and injuries.

A specific taxonomy has been introduced which refers to main causal factors triggering an injury or a precursor event; two main categories have been introduced: the risk source and the type of causes categories. The taxonomy aims to support a fast categorization of accident precursor as well as injury events directly collected in field in a specific time window. It has to be noted that the taxonomy proposed in the case study could vary according to a different application in a different firm, but this does not affect the overall validity of the approach.

The "risk source" category refers to the main element (a procedure, an equipment, etc.) causing the negative event. The proposed taxonomy has been deducted from the firm risk analysis document which defines workplace risk source based on their specific types. Risk sources are classified on the basis of their function at the workplace, e.g. safety devices or production equipment. Thus, based on interviews developed with firm safety managers, five main categories have been introduced:

- *Handling systems*: it refers to equipment applied for moving products and goods, such as forklifts, trans-pallets, etc.
- *Equipment*: it mainly refers to machines and devices used during working, such as tools, disassembly kits, etc.
- *Utilities*: it refers to firm assets, such as stairs, doors, air conditioners, etc.
- *Safety devices*: it refers to individual and collective safety devices, such as safety helmets, goggles, emergency buttons, etc.
- *Work procedures*: it affects the organizational system, such as processing procedures, tasks, etc.

The "cause type " category outlines causal factors that have led to each analyzed event.

Based on firm safety experience, four categories have been introduced:

- *Instability*: it refers to an incorrect positioning of an item as well as a worker during a movement action. One example is an heavy weight in a forklift which has lead to a tipping.
- *Defectiveness*: it refers to a fault of a device and an action; it mainly refers to an intrinsic technical fault, but an incorrect design of a procedure could be also included. One example is a breakdown of an emergency button.
- *Layout*: it refers to a not correct (or ineffective) localization of an equipment or a system. For instance, a localization of a fire extinguisher next to a shelving.

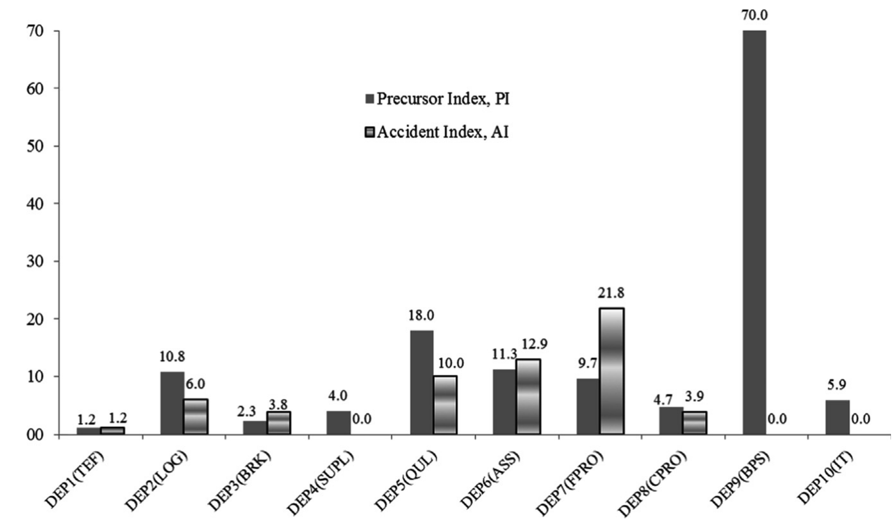

Fig. 4. Distribution of PI and AI values for each department in analysis.

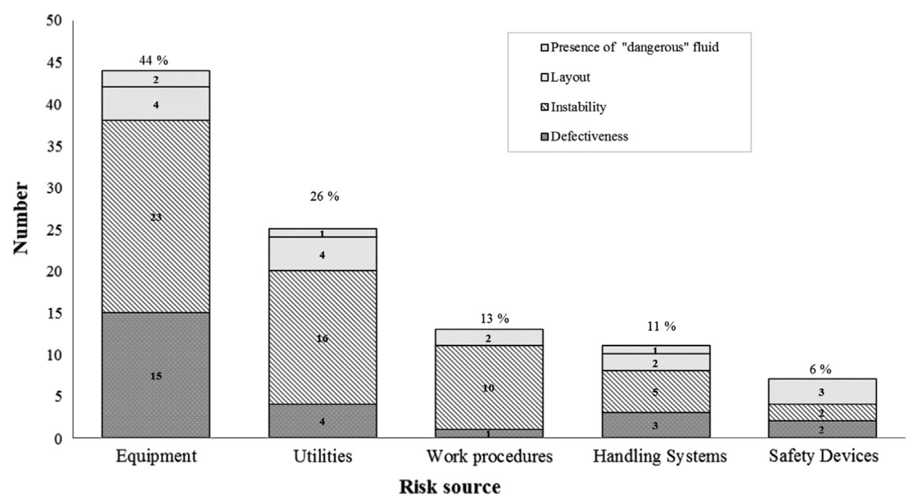

Fig. 5. Classification of accident precursor events based on the proposed taxonomy.

- *Presence of "dangerous" fluid*: it refers to a release of such material, which could trigger to a negative event for workers (e.g. an oil loss near to a working machine).

Cause type categories previously described have been deducted by several interviews of firm safety managers: these categories represent main causes deducted from past occurred injuries by analyzing them through a root cause analysis process.

At first, a more aggregate analysis has been carried out: each reported precursor and occurred injury event has been manually analyzed and classified in collaboration with firm safety managers based on this taxonomy. Results about accident precursor and injury events are in Figs. 5 and 6, respectively.

By analyzing aggregate data on precursor events, the "Equipment" category has confirmed as the most frequent risk source (with a 44% of total data) characterizing precursor events; the second one is the "utilities" category (with about 26% of total data). Lower values (about 13% and 6%) have been estimated for "safety devices" and "work procedures". Same results have been obtained by analyzing data regarding the "cause type" factor: "instability" and "defectiveness" are the most important causal factors in reported precursor events. A less criticality has been estimated to "Layout" (15% of the sample) and to "the presence of dangerous fluid" (4% of the total sample).

By crossing aggregate data about precursor and injury events, one common issue is that "instability" revealed as a very critical causal factor in the firm: defectiveness in work procedures is one key condition leading to high consequences for workers.

Next, data have been detailed for each firm area; results are reported in Table 1.

Starting to analyze their distribution according to the "risk source" factor, results outline common causal factors (i.e. "equipment" and "work procedures" respectively) for precursor and injuries events only in three departments, such as Department 3, 8, and 5. On the other hand, the previous trend could not be clearly highlighted for Department 1, 2, 6, 7. By focusing on the two more critical departments – i.e. Department 6 and 7 as outlined by the previous analysis –, an interesting result has been obtained: the most outlined risk source factor for injury events is for both two the "working procedures" (3 out of 7 accidents for Department 6, and, 5 out of 7 accidents for Department 7, respectively). This result could be mainly due to the relative high presence of semi-manual and manual machines and operations characterizing these two plant areas. An opposite result has been estimated for precursor events where "equipment" has been outlined as the main risk source.

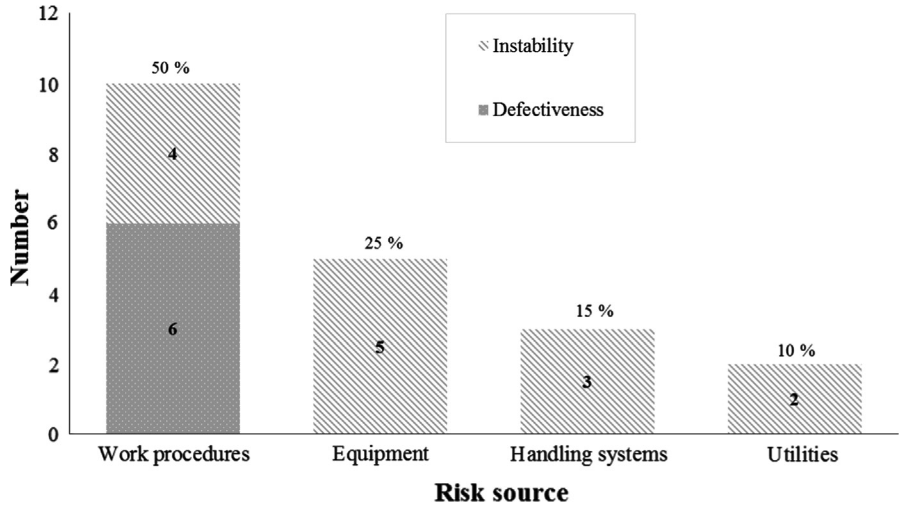

Fig. 6. Classification of injury events reported in 2012 based on the proposed taxonomy.

Remarkable is the low number of reported unsafe acts where "work procedures" have been defined as a risk source: this result confirms the relatively low propensity of workers to report as unsafe behaviors involving directly other workers [28], even if work procedures represent a critical risk source for their departments. These "discrepancies" between data about precursor and injury event outline relevant points of intervention to be developed by the firm management for improving NMS effectiveness in these departments, and consequently, overall firm safety levels.

Furthermore, DEP1 and DEP2 don't present a predominant tendency probably due to the total low number of analyzed events: thus, intervention actions could not be evaluated as urgent as the previous ones.

By analyzing the second causal factor – i.e. the "type of cause" category – defined in the proposed taxonomy two main trends could be outlined:

- A direct relationship might be highlighted for Department 3, 6, 7, and 8, where the largest number of reported injury events (100% for DEP6, DEP8, DEP3 and about 60% for DEP7) is characterized by "instability" as a root cause as well as the most number of reported precursor events (62% for Department 6, 61 for Department 7, and about 60% and 50% for Department 8 and 3, respectively).
- This trend could not be outlined for DEP2 and DEP5, where "defectiveness" has revealed as a main root cause for occurred injury events, although "instability" is the main root cause reported for precursor events.

4.3. Statistical analysis

A statistical analysis has been carried out aiming to outline significant relationships between risk source and type of cause categories for both precursor and injury events. The statistical analysis has been carried out by applying a well-known test, i.e. the Friedman test [7,32], a non-parametric test (distribution-free) applied similarly to ANOVA test with two factors. This test uses the ranks of the data rather than their raw values to calculate the statistic similarly to many non-parametric tests. The aim of the test is to verify the null hypothesis (H_0), such as the distributions are the same across repeated observations. In detail, if the H_0 hypothesis is true, no specific relationship could be outlined between "risk source" and "type of cause" categories, while if H_0 hypothesis is false, a relationship could be outlined.

Thus, the aim of its application in this specific case is to verify by a quantitative method whether a clear relationship between accident precursors and injuries can be outlined by analyzing different causal factors (i.e. event cause and source). The test is based on calculating the Fr index which is defined in Eq. (3)

$$Fr = \sum_{i=1}^{k}\left(T_i - \frac{N(k+1)}{2}\right)^2 \tag{3}$$

where k is the column number and N is the row number evaluated in the statistical matrix, and T_i is the ith rank value observed. The test aims to evaluate the ratings of N "blocks" on k "treatments".

In order to verify the H_0 hypothesis, Fr values have to be compared to critical ones (Fr_{CR}): in the case of small samples (i.e. $k=3$ and $N \le 15$ or $k=4$ and $N \le 9$), critical values of the statistic are provided by specific tables defined by Friedman. On the other hand, critical values for large samples ($k \ge 5$) have been deducted by the Chi-Square Distribution with $(k-1)$ degrees of freedom; the coherence value χ^2_F is defined in Eq. (4)

$$Fr_{CR} \cong \chi^2_F = \frac{12}{Nk(k+1)} \sum_{i=1}^{k}\left(T_i - \frac{N(k+1)}{2}\right)^2 \tag{4}$$

Thus, if $Fr < Fr_{CR}$, the H_0 hypothesis is true; thus, the k treatments do not affect the distribution of N observed block values.

In order to analyze all possible combinations of collected data, four cases have been defined. Details are described as follows.

Case #1. "type of cause" categories represent the kth column ($k=4$) and "risk source" categories are the Nth row ($N=5$) and the data sample is the total number of accident precursor events. Estimated Fr values are in Table 2: each ranking value is reported in brackets. Due to a small sample in analysis, the statistics F_r has been defined by Friedman values: the critical value is equal to 94.5. The critical value Fr_{CR} in this case is equal to 65 for $\alpha=0.05$; thus, the H_0 hypothesis is true. A predominant tendency in terms of rank concentration in a specific cause type could not be outlined in this case; thus, types of cause are not directly connected to a specific risk source for precursor events.

Case #2. "risk source" categories are the kth column ($k=5$); "type of Cause" categories are the Nth row ($N=4$), and the data sample is the total number of accident precursor events. Estimated values are in Table 3: each ranking value is reported in brackets. Differently from the previous case, the significance analysis is now based on the Chi-square distribution: the critical value $\chi^2_{F_{CR}}$

Table 1
Data distribution for each firm department.

	Event type	DEP1	DEP2	DEP3	DEP4	DEP5	DEP6	DEP7	DEP8	DEP9	DEP10	Total
Risk sources	**Injuries**	**2**	**1**	**1**	**0**	**1**	**7**	**7**	**1**	**0**	**0**	**20**
	Handling systems	0	0	0	0	0	2	1	0	0	0	3
	Equipment	2	0	1	0	0	1	0	1	0	0	5
	Utilities	0	0	0	0	0	1	1	0	0	0	2
	Work procedures	0	1	0	0	1	3	5	0	0	0	10
	Safety devices	0	0	0	0	0	0	0	0	0	0	0
Cause type	*Instability*	2	0	1	0	0	7	4	1	0	0	15
	Layout	0	0	0	0	0	0	0	0	0	0	0
	Presence of "dangerous" fluid	0	0	0	0	0	0	0	0	0	0	0
	Defectiveness	0	1	0	0	1	0	3	0	0	0	5
Risk sources	**Unsafe Act**	**0**	**0**	**0**	**0**	**2**	**4**	**0**	**0**	**0**	**0**	**6**
	Handling systems	0	0	0	0	0	0	0	0	0	0	0
	Equipment	0	0	0	0	0	1	0	0	0	0	1
	Utilities	0	0	0	0	0	0	0	0	0	0	0
	Work procedures	0	0	0	0	2	2	0	0	0	0	4
	Safety devices	0	0	0	0	0	1	0	0	0	0	1
Cause type	*Instability*	0	0	0	0	2	2	0	0	0	0	4
	Layout	0	0	0	0	0	1	0	0	0	0	1
	Presence of "dangerous" fluid	0	0	0	0	0	0	0	0	0	0	0
	Defectiveness	0	0	0	0	0	1	0	0	0	0	1
Risk sources	**Unsafe conditions**	**2**	**12**	**5**	**1**	**12**	**48**	**28**	**8**	**6**	**1**	**123**
	Handling systems	0	1	1	0	0	7	3	1	0	0	13
	Equipment	0	3	2	0	3	28	11	4	2	0	53
	Utilities	2	7	2	1	3	6	4	3	4	1	33
	Work procedures	0	1	0	0	2	7	5	0	0	0	15
	Safety devices	0	0	0	0	4	0	5	0	0	0	9
Cause type	*Instability*	1	7	3	0	5	30	17	4	3	1	71
	Layout	0	3	1	1	5	3	4	1	0	0	18
	Presence of "dangerous" fluid	0	0	1	0	1	2	2	0	0	0	6
	Defectiveness	1	2	0	0	1	13	5	3	3	0	28
Risk sources	**Near miss**	**0**	**6**	**1**	**2**	**4**	**9**	**3**	**4**	**1**	**0**	**30**
	Handling systems	0	1	0	1	0	0	0	3	0	0	5
	Equipment	0	2	1	1	1	6	3	1	0	0	15
	Utilities	0	3	0	0	2	2	0	0	1	0	8
	Work procedures	0	0	0	0	1	1	0	0	0	0	2
	Safety devices	0	0	0	0	0	0	0	0	0	0	0
Cause type	*Instability*	0	4	0	1	1	6	2	3	0	0	17
	Layout	0	1	0	0	2	0	0	0	0	0	3
	Presence of "dangerous" fluid	0	0	0	0	0	0	0	0	0	0	0
	Defectiveness	0	1	1	1	1	3	1	1	1	0	10

Table 2
Test values estimated for Case #1.

Risk source (*N*)	**Type of cause (*k*)**			
	Defectiveness	Instability	Layout	Presence of "dangerous" fluid
Equipment	24 (3)	37 (4)	6 (2)	3 (1)
Utilities	6 (2)	26 (4)	7 (3)	2 (1)
Work procedures	1 (2)	16 (4)	3 (3)	0 (1)
Handling systems	6 (3)	8 (4)	3 (2)	1 (1)
Safety devices	3 (2.5)	3 (2.5)	4 (4)	0 (1)
Total	**40 (12.5)**	**90 (18.5)**	**23 (14)**	**6 (5)**
Estimated *Fr* value	**94.5**			

Table 3
Test values estimated for Case #2.

Type of cause (*N*)	**Risk source (*k*)**				
	Equipment	Utilities	Work procedures	Handling Systems	Safety devices
Defectiveness	24 (5)	6 (3.5)	1 (1)	6 (3.5)	3 (2)
Instability	37 (5)	26 (4)	16 (3)	8 (2)	3 (1)
Layout	6 (4)	7 (5)	3 (1.5)	3 (1.5)	4 (3)
Presence of "dangerous" fluid	3 (5)	2 (4)	0 (1.5)	1 (3)	0 (1.5)
Total value	**70 (19)**	**41 (16.5)**	**20 (7)**	**18 (10)**	**10 (7.5)**
Estimated *Fr* value	**11.85**				

for $k=5$ and $\alpha=0.05$ is equal to 9.49; thus, as the estimated value is greater than the critical one, the H_0 hypothesis is true.

Case #3. "type of cause" categories represent the kth column ($\mathbf{k}=4$) and "risk source" categories are the Nth row ($N=5$) but data source is the occurred injury event sample. Estimated values are in Table 4. The critical value Fr_{CR} for $k=4$ and $N=5$ is equal to 65 for $\alpha=0.05$; as $Fr < Fr_{CR}$, the H_0 hypothesis is false: a relationship between types of causes and risk sources can be highlighted. A large concentration of values in one main risk source category has been obtained: the higher observed Ti value highlights "Instability" (i.e. 17.5) as the most critical risk source category. This information will allow to support urgent intervention and/or actions for reducing its hazard.

Table 4
Test values estimated for Case #3.

Risk source (N)	Type of cause (k)			
	Defectiveness	Instability	Layout	Presence of "dangerous" fluid
Equipment	0 (2)	5 (4)	0 (2)	0 (2)
Utilities	0 (2)	2 (4)	0 (2)	0 (2)
Work procedures	6 (4)	4 (3)	0 (1.5)	0 (1.5)
Handling systems	0 (2)	3 (4)	0 (2)	0 (2)
Safety devices	0 (2.5)	0 (2.5)	0 (2.5)	0 (2.5)
Total	**6** (**12.5**)	**14** (**17.5**)	**0** (**10**)	**0** (**10**)
Estimated *Fr* value	**37.5**			

Case #4. input data are occurred injury events; "risk source" categories are the kth column ($k=5$) and "type of Cause" categories are the Nth row ($N=4$) have been analyzed; results are in Table 4. Similarly to case #2, the Chi-square distribution has been applied for coherence analysis; the critical value $\chi^2_{F_{CR}}$ is equal to 9.49 for $\alpha=0.05$; thus, the H_0 hypothesis is false. A slight trend in terms of rank value concentration in a specific risk source category – i.e. the "work procedures" – could be outlined thus confirming it as the most critical risk source in the firm.

In conclusion, the statistical analysis – even if the sample is not too large – has confirmed results obtained in Section 3.2: "work procedures" represent an underestimated risk source in the firm. Based on these results, the firm safety management has started to plan training campaigns tailored on each specific critical issues outlined by the previous analysis involving workers in the most critical firm areas.

This result confirms the overall efficacy of the proposed model as it allowed to verify the global effectiveness of the current NMS and, in addition, it provided critical points where re-design interventions are required. It has to be noted that the proposed analysis does not aim to achieve a general statistical validity, but the main purpose is to test the framework proposed for "measuring" the global NMS effectiveness.

5. Discussion

NMSs are generally recognized as tools for preventing accidents as they provide knowledge for identifying and eliminating common causes of accidents before the loss occurs. The idea proposed in this study is that an effective NMS provides opportunities to improve organizational safety performance: thus, evaluating the effectiveness of the NMS is important for controlling safety levels. The study has outlined several issues which are discussed as follows:

- First of all, by applying lean safety paradigm, precursor events (near miss, unsafe acts and conditions) are outlined as relevant indicators due to their capability to support prevention activities before a real accident occurs. Thus, controlling performance of the firm NMS is an important activity: controlling how the near miss reporting system is working in an organization outlines the willingness to signal of employers, but it also points out the overall involvement of employers in safety prevention. As no metrics are available to measure this performance, the study has proposed a systematic approach based on integrate analysis of precursor events and occurred injuries at workplace. The framework has a twofold purpose: a quantitative measurement, based on an index analysis, allows to verify NMS performance in involving employers in the precursor events reporting process and a measurement of the NMS efficacy in preventing accidents, which is its main target.
- Results provided by the case study confirm this issue: based on proposed index analysis, most hazardous working areas based on injury rates are also characterized by a lower tendency to record precursor events, especially ones based on a not correct human behavior (i.e. unsafe acts). The forcing idea is that there is a sort of linear – but not a direct proportion – relationship between precursor events and accident. Negative feedbacks about NMS performance will be evaluated if AI value is larger than PI value in such an area: these feedbacks provide safety managers with tailored information where major efforts are required to increase proactive behaviors of employers towards safety issues (e.g. in terms of willingness to report). As an example, if during a time interval, AI values will decrease together with estimated PI values, positive feedbacks could be outlined for the NMS. Furthermore, a long trend with AI rate values equal to zero and low PI values outline that a firm has "used" effectively its NMS for preventing accidents: in this case, employers efficiently report precursors events, and, the company acts effectively to remove causes that have generated precursor events.
- The cross analysis between causes which have led to injuries and precursor events allows to provide information about critical point of intervention where the firm has to act to impact heavily for preventing accidents. Results deducted by the case study are relevant not for their statistical significance, but for the feedbacks they provide to firm safety managers in designing more effective interventions activities. Thus, the model application has outlined specific risk sources and hazards for each critical working area, thus allowing safety managers to orient better their efforts in prevention activities.

Based on this approach, the NMS will become an effective and predictive safety tool based on actual data derived directly from the workplace. However, it has to be noted that recording and analyzing precursor events do not completely prevent from accidents: however, it could be avoided most predictable ones based on actual conditions of the workplace. Measuring performance of a NMS is a way to apply proactive strategies for preventing accidents.

Finally, further development could be oriented to introduce information derived from the NMS to update firm risk analysis thus allowing to provide a sort of "condition-based" risk analysis based on feedback derived directly from the operational field.

6. Conclusions

NMSs are becoming wide-spread in several industrial contexts although their first application is started in high hazardous industries, but they are required by international standards about safety management systems. Near-misses are accident precursors as they outline weak signals that have to be controlled for improving safety levels at workplace. Furthermore, based on a proactive point of view, they represent an important source of knowledge for monitoring safety levels of a firm. Precursor and injury events are usually characterized by common causes; this concept has been confirmed by recent studies which have proposed a joint analysis of accidents and near-misses. However, structured approaches for measuring the global effectiveness of a NMS applied in firm are not yet been fully proposed. The paper proposes a general framework for evaluating overall performance of a NMS: the framework has been designed according to lean safety approach, which is a global strategy to improve organizational process effectiveness. The aim of this study is twofold: defining a structured approach for performance measurement analysis to assess its effectiveness, and verifying the actual contribution of the NMS in improving occupational safety levels. The proposed framework has been applied in a real case study regarding an automotive firm supplier. Its application in the case study has revealed effective by outlining criticalities as well as continuous improvement points which have supported follow up activities of firm NMS. In conclusion, the proposed framework is characterized by a general efficacy as it will be suitable not only to verify performance of NMSs, but also to provide a structured approach for analyzing accident precursor events. Further developments will be oriented to define more automatic tools for analyzing reported events, e.g. based on semantic models, aiming to improve the classification process of both accident precursor and injury events.

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