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Optimization of Construction Site Safety Supervision Activities

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Abstract

A proposed safety management methodology for large and complex construction sites is presented. The methodology includes a risk control process based on continuous improvement, which utilizes data collected in an audit program to evaluate the safety performance of different crews on site. The methodology utilizes information on ratios that can be determined between different types of safety events in order to identify deviations that require control actions, and in order to reduce the number of severe safety events by reducing the number of unsafe acts that lead to such events.

Keywords: Construction safety; Optimization; Site supervision; Statistical analysis

1. Introduction

Many safety management methods that are applied on construction sites are in essence retroactive. Such methods include, for example, disciplinary actions against employees violating safety requirements, safety-event investigations, performing coaching and teaching after the occurrence of an unwanted event, etc. It appears that the larger and more complex the construction site is, the larger is the gap between the need to reach an adequate safety level on the site and the actual ability to achieve and maintain this. As sites increase in size and complexity, additional management tools are required to ensure safety.

An alternative approach is that of pro-active safety management. In this approach technological tools and methodological approaches are used in order to raise safety levels, by initiating activities to prevent safety events rather than merely reacting to them. Examples for implementing this approach are:

Performing safety audits throughout the site and identifying trends. Once the problematic sites and locations are identified, additional supervision and coaching will be executed at those specific locations.

Using safety indicators to evaluate performances.

Data mining of the results of safety audits.

Using automated optimization to determine the most efficient supervision method for increasing compliance.

Supervision and on-the-spot coaching is a good tool for enforcing compliance and reducing safety risk levels. In this research, a methodology for maximizing safety supervision abilities is being developed. By ranking specific features of an activity (based on observation, statistics, expert knowledge, etc.) an objective evaluation of the activity's risk-level can be performed. Using the methodology, one can decide which activities require additional supervision, and which activities should be supervised first to achieve the most efficient results. An application of this method may maximize the influence of the on-field staff by helping them to reduce the risk level of dangerous activities, reducing the amount and severity of safety events, and helping to achieve improved safety performances.

1.1. *Traditional methods for maintaining a safe construction site*

A significant number of studies have been carried out to develop tools and models for the planning of safe construction sites. Rozenfeld et al. [1] developed a Construction Job Safety Analysis tool, which focused on the identification of potential loss of-control events for a detailed planning of construction activities, based on data

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collected through interviews. Mitropoulos et al. [2] presented a model of the factors affecting the likelihood of accidents during a construction activity. The model focuses on the characteristics of a project that generate hazardous situations and shape actual work behaviors, and analyzes the conditions that trigger the release of the hazards. Saurin et al. [3] defined a Safety Planning and Control Model that includes three hierarchical levels, for long-, medium-, and short-term safety planning. Proactive and reactive performance indicators were defined for safety control and evaluation, based on the percentage of safe work packages and actual accident data. Jannadi and Almishari [4] developed a risk assessor model [5].

One of the most common methods to manage safety programs is the risk management process. In this method the generated risk level is controlled and reduced to an acceptable level. It is a 3-step process:

- Identification of the risk generated by the activities, the site conditions, etc.
- Evaluation of the identified risks, where the main factors are the probability that the accident will occur if the activity is performed in a particular manner, and the level of severity of the results in case of an occurrence.
- Risk control: in this step it is required to come up with risk reductions and control means to reduce the probability, the severity, or both. Examples of such means can be adding Personal Protective Equipment (PPE) for specific activities, usage of fall protection equipment, using tool secure devices, etc, [6].

A common approach to accident prevention is based on OSHA's violations approach and focuses on prescribing and enforcing "defenses;" that is, physical and procedural barriers that reduce the workers' exposure to hazards [2], other means to raise safety level are having of a training program generated and modified to the site needs and features. The training program can also be modified according to the employee's scope and planned activities, other methods that were found efficient are - Tool Box meetings to raise awareness and communicate information to the employees, PTP, having a designated safety officer on site, safety orientation, and performing drugs and alcohol tests [7].

1.2. *Managing safety in large scale construction sites*

The safety management tools mentioned above can enable a sufficient level of safety on small-scale construction sites. That's been said, it is known that the construction is one of the most dangerous industries world-wide [3], therefor when discussing big sites which contain many crews from a variety of disciplines, belonging to different companies and contractors and with differing standards and commitments towards safety, it is a significant challenge to define a unified safety standard and to enforce and verify that all the safety requirements are being fulfilled. In these cases, additional safety management tools are required.

A commonly used tool for this purpose is to carry out a safety observation program. The purpose of the audits is to examine whether all safety requirements are being implemented on site. Employees and contractors that display good performances receive positive feedbacks and are awarded, while contractors that are observed to violate safety requirements are exposed to punishments and to disciplinary actions.

In order to prevent the reoccurrence of unwanted safety events, good communication and calibration need to be kept. Therefore, after the occurrence of a safety event, the relevant contractor is required to publish a lessons-learned paper specifying the conditions and sequence of events that led to the safety event occurrence. This way, other contractors that are performing similar activities and exposed to similar risks can learn and prevent the next event and increase the general safety level of the whole site.

It may appear as if the requirements that will lead to a safe construction site are quite clear. Yet, two factors jointly make it difficult to obtain this goal. The first factor is that that there are limited safety supervision resources (safety personnel). Therefore, their ability to influence and prevent safety violations is limited. The second factor is that construction sites are dynamic, ever changing, have multiple high risk activities that are executed in parallel and have changing environmental conditions. The combination of these two factors leads to the understanding that the risk control process has to be continuous and dynamic, so that the activities with the highest risk at a given time will be controlled and monitored.

2. Proposed methodology

On complex construction sites, where sub-contractors with different safety standards are hired, a lack of clarity often exists regarding the safety expectations and requirements. This research seeks to develop a safety management methodology in order to minimize this lack of clarity and in order to verify that all the crews on site are in compliance with the safety requirements.

The proposed methodology includes a risk control process based on continuous improvement, combined with the maintenance of an audit program that will help to better evaluate the safety performances and will enable the evaluation at any time of locations that require additional supervision, coaching and support. This approach is based on a Plan Act Do Check (PADC) methodology (Figure 1).

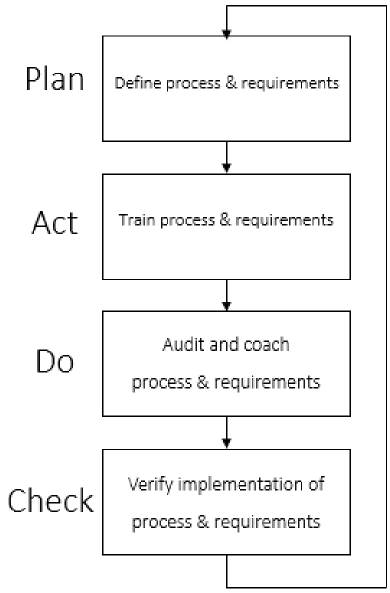

Figure 1: PADC methodology for continuous safety management process

In this methodology, the risk management process is carried out in parallel with the approval of activities. Supervision resources are allocated in accordance with the risk control plan to ensure maximum impact. While activities are being executed, safety audits are conducted to analyze and evaluate safety and compliance performances. According to the results of these audits, the means of improvement (e.g. training, on-site coaching, disciplinary actions, etc.) are planned and implemented.

The methodology helps to define the construction site's safety level by using time-dependent variables to describe the crews, and quantifies and ranks features that may predict their risk exposure and the probability of the occurrence of a safety event. These variables include the crew's learning curve, its experience, safety training, management commitment, etc. The planning and implementation of the methodology is oriented towards constant improvement and maximum benefit from the actions of the safety staff. The methodology includes assigning the staff to the appropriate locations, a constant reevaluation of safety needs, and continuous risk evaluation.

2.1. *Implementation of the methodology*

The first phase of the methodology is to define the safety requirements and expectations while executing an activity. These requirements may come from standards, regulations, the company's requirements, past experience of similar operations, etc.

The second phase includes training prior to the actual execution of the activity. The duration, method of training, and other requirements will be determined according to the complexity of the activity and the level of risk.

The third phase takes place while the activity is being executed on site. Safety audit teams evaluate the performances of crews, and check if the safety requirements are being implemented. In general, good performances will be rewarded and encouraged, while poor performances will lead to on-site training (or stopping the work in case of major violations). Another purpose of this phase is to determine if the activity is planned in a controlled manner and if additional safety means are required. The audit data will be stored and the managers of the crews will be informed of the safety outcomes.

The fourth and final phase of the methodology includes managerial safety audits. The purpose of these audits is to ensure the implementation of additional requirements (if there are any) and to evaluate the need for changes in the plans.

2.2. *The safety pyramid model*

In his book "Accident Prevention: A Scientific Approach", Heinrich [8] established a "safety pyramid" model to describe the ratio between different types of safety events in the manufacturing industry. According to this study, safety events occur in the industry at a ratio of 1 major injury or death for every 29 minor injuries, and for every 300 "near misses". Later studies divided the pyramid into 5 layers:

- Unsafe act or condition
- Near miss
- First aid
- Recordable injury
- Fatality.

In additional to determining the different layers of the pyramid, these studies indicated that there is a constant ratio between the layers. According to Bird [9], the ratio between the pyramid layers is 1-10-30-600, which means that for every one fatality or severe injury event, there are 10 first aid events, 30 events of impact or damage to equipment, and 600 near misses. The safety pyramid model was developed for the manufacturing industry, which has different features than the construction industry. Therefore, statistical data on the safety events in a large-scale construction site were analyzed in this research in order to see if there are any differences with the existing model, and what are their sources.

Dividing the safety events using a pyramid model emphasizes the idea that a severe safety event is not an act of god. Prior to this event many smaller events will have occurred, and if the organization would have understood their statistical significance it might have prevented the event from happening. Statistically analyzing the data could thus help to identify when the data starts to reflect poor safety performances. The implementation of the proposed methodology will be based on establishing an acceptable level of safety performance for each level of the safety pyramid, and on the constant review of the observed performances on site. Whenever the occurrence of any type of safety event will exceed the acceptable value, a corrective action plan will need to be executed in order to improve the performances and to prevent the occurrence of a higher-level safety event.

In many cases the safety level of a site or type of activity is evaluated by the question if there were fatalities and injuries [6], and their rate. However, a fatal event is just the tip of the iceberg, and it is usually preceded by a large number of unsafe acts and conditions and many low severity safety events. Therefore, it is suggested that safety levels should be evaluated by examining all safety layers, and not just the upper one. In order to do so, it is required to determine the acceptable relative number of events in each layer. Once the safety performances deviate from this number, action is required to improve the performances. Furthermore, since previous studies indicate that there is a constant ratio between the different safety layers, it can be hypothesized that a reduction of the number of events in the lowest layer (unsafe act or condition) will proportionally decrease all the layers above it, and that fewer safety events will occur, both in terms of quantity and severity.

2.3. *Preliminary findings*

Based on the safety audits that were performed in a large-scale construction site, initial findings indicate that in terms of the ratios of events, the construction industry appears to differ from the manufacturing industry. In this case study, approximately 2600 safety audits were made. In the majority of audits the results were "no safety violations". The outcomes of the remaining audits and the project safety log were analyzed and are summarized in Table 1 and Figure 2.

Table 1. Results obtained in the case study.

Safety event type	#	Factor of proportionality	Percentile
Unsafe act / Condition	950	-	87.2
Near miss	84	11.3	7.7
First Aid	47	1.8	4.3
Injury	8	5.9	0.7
Severe injury / Death	1	8.0	0.1

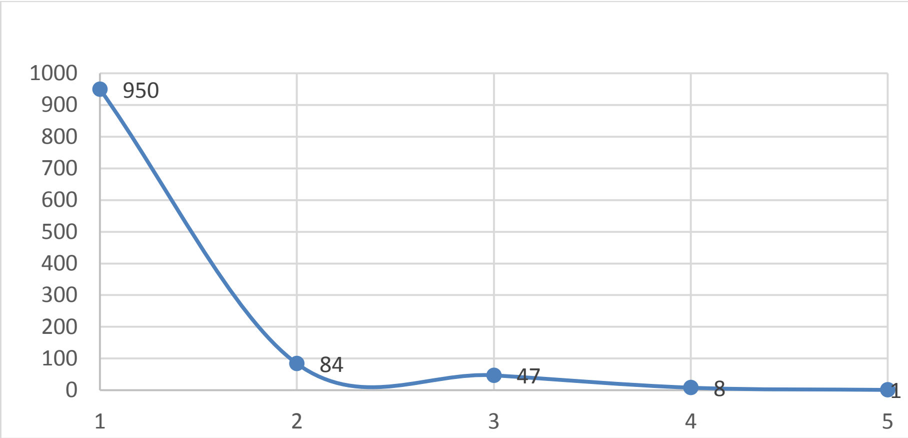

Figure 2: The number of safety events in the case study

These results reflect the safety performances of the sub-contractors from all the different disciplines of construction, such as civil, electric, piping, mechanical, architectural, etc. It can be observed from the factors of proportionality that were calculated that the biggest difference from the conventional models is between the first aid events and the near miss events. While the traditional model predicts a ratio of 1:10, the ratio in this project was 1:1.8. In other words, many more first aid events occurred than would be predicted based on the traditional model

Based on the findings in the case study, specific statistical values can be defined for each type of safety event, which represent the acceptable relative level of occurrence for these events. These values are represented by the calculated percentiles in Table 1 and Figure 3. Continuous monitoring of the site will identify the actual number of events in each category. Any deviation that is observed on the construction site will require the implementation of safety measures.

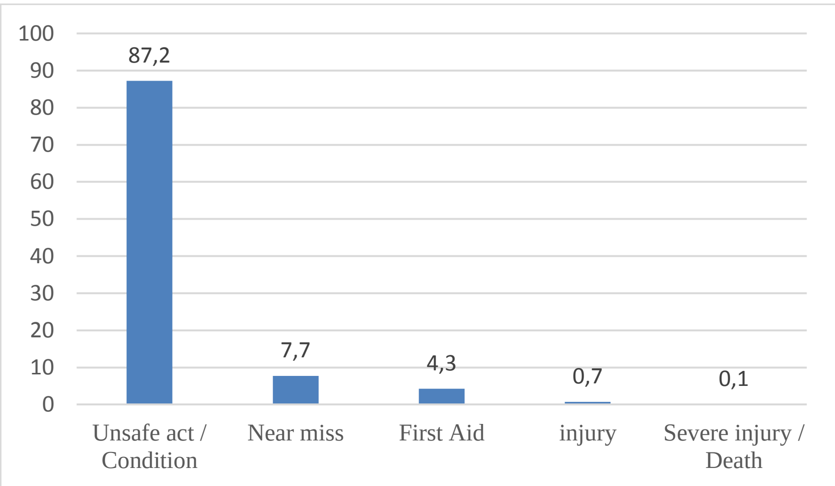

Figure 3: Acceptable relative level of occurrence of safety events

3. Conclusions and further research

A proposed safety management methodology has been presented for large and complex construction sites. The methodology includes a risk control process based on continuous improvement, which utilizes data collected in an audit program to evaluate the safety performance of different crews on site. The methodology utilizes information on ratios that can be determined between different types of safety events in order to identify deviations that require control actions, and in order to reduce the number of severe safety events by reducing the number of unsafe acts that lead to such events.

Initial findings of safety audits that were performed in a large-scale construction site indicate that the construction industry appears to differ from the manufacturing industry in terms of the ratios of safety events. However, additional research is being carried out in order to verify these results.

Further research is being carried out to develop the proposed methodology. This research includes the development of a process to calculate the risk posed by specific activities, based on data that is collected in real-time. In addition, a process is being developed for the definition of safe work areas and the required distances between crews at any time during the project, in order to reduce the impact of safety events.

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