An Algorithm for Classifying Error Types of Front-Line Workers: A Case Study of Occupational Accidents in Construction Sites

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Abstract

The objective of this study is to propose improvements in an algorithm for classifying error types of front-line workers. The improvements have been identified on the basis of testing the algorithm on construction sites, an environment in which it had not yet been implemented. Thus, 19 occupational accidents which occurred in a small-sized construction company were investigated and the error types of both workers and crew members who had been injured were classified. The results indicated that there was no human error in 70.5% of the 34 times in which the algorithm was applied, providing evidence that the causes were strongly linked to work system design rather than specific behaviours of workers. Moreover, the study makes recommendations to facilitate the interpretation of questions that form part of the algorithm and proposes changes to some questions in comparison with earlier versions of this tool.

Keywords: accident investigation, human error, safety.
1. Introduction

The literature points out that each type of human error has certain causal patterns, which means that preventive actions should have different emphases for each type of error (Reason, 2008). For example, the use of error-proof devices is particularly recommended for tackling memory lapses and slips, since these types of errors occur when behaviours become automated and, such devices, by definition, operate independently of the operators' attention span. As to violations, characterized by deliberate deviations from safe working practices, they typically require improvements in procedures or improvements in safety culture (Saurin et al., 2008).

Therefore, knowledge of the most frequent error types, especially based on data which allow long-term trends to be identified, is important information for the design of health and safety at work (HSW) management systems. The classifications of error types are useful as they make it viable to organize data and as they contribute to our understanding of the modes through which errors are caused and how they can be prevented (Sanders and McCormick, 1993). However, the literature offers few methods to minimize the subjectivity involved in classifying an error. This might be a source of unreliability when human error data are analysed and tabulated (Grabowski et al., 2009).

Baker and Krokos (2007) also criticize the lack of methods for comparing different classifications, such a lack making it difficult to identify which are best for what purpose. Among the methods available for classifying errors, this study addresses the one put forward by Saurin et al. (2008), which was originally drawn up and tested in order to analyse accidents both in a factory making agricultural equipment and in a fuel distribution company. Basically, the method consists of an algorithm with a series of questions, with answers of the yes or no type, which allows the error types by frontline operators to be classified, based on the SRK (skill, rule and knowledge) classification put forward by Reason (1990) and Reason (1997). In this classification, the errors are differentiated according to the levels of cognitive performance at which they occur, thus providing a more abstract classification than those based on observable characteristics of behaviour (e.g. omissions and repetitions) as well as classifications that highlight local contextual factors contextual, such as stress, interruptions and distractions (Reason, 2008).

It is against this background that this study sets out to make recommendations to facilitate the application and interpretation of questions of the algorithm, since studies conducted hitherto have indicated difficulties of this nature. Improvements in the algorithm were identified based on applying them to the investigation of occupational accidents in the construction industry, an environment in which they had not hitherto been tested.

Moreover, unlike the previous applications, the researchers were able to interview all the workers who had been injured, while what were not used were reports of investigations by the company, as no investigations had taken place. Thus, the context of applying the tool was clearly different from the earlier studies, which contributed to identifying opportunities for improvement. Moreover, applying the algorithm generated exploratory data, which are scarce in the literature, on the most frequent error types among construction workers.
2. Definition of human error and classification of error types adopted in this study

In this study, it is considered that a human error has one or both of the following characteristics: (a) there was a deviation with regard to the correct method of execution, assuming that those who were performing the task had the resources available to carry out the correct method; or (b) a wrong decision was taken, assuming that resources for making the correct decision were available. It is worth noting that the definition adopted does not necessarily mean that a human error leads to undesirable results, since chance can lead to good results even if there were faults in planning or implementation.

As previously mentioned, this study adopts the SRK classification proposed by Reason (1990) and Reason (1997), which divides errors into three categories:

(a) skill-based errors (SB): at this level, the operator uses automatic and routine behaviours, with a low level of awareness. The errors typically involve failures of execution, lapses and slips being the most common. While lapses generally involve failures of memory, slips are associated with failures to recognize signs and disturbances of any kind that disrupt automatic behaviours. Lapses or slips occur prior to the detection of a problem;

(b) rule-based errors (RB): at this level, operators raise their awareness in order to apply familiar rules to deviations which are also familiar in routine situations. Three basic types of failures may occur at the RB level: application of a bad rule; application of a good rule, but inappropriate to the situation in question; non-application of a good rule. In this study, only this latter type of RB failure is considered as one type of error of front-line operators, it being designated by the term violation. It is assumed that the application of bad rules, or the application of a good rule inappropriate to the context, are types of errors that should be allocated to more senior levels in the hierarchy who are responsible for conceiving of the rules;

(c) knowledge-based errors (KB): at this level the operator acts at a high level of awareness to solve problems for which there are no rules. Errors are very likely when the operator is required to operate at this level, because, among other reasons, there are usually organizational pressures that limit the time and resources for decision making.

3. Algorithm for classifying error types

The algorithm proposed by Saurin et al. (2008) consists of ten questions, which can lead to five types of final answers (Figure 1): slips, memory lapses, violations, knowledge-based errors, and there was no worker error. Question 1 was expressed as follows: "was the worker aware of the procedures content and/or was he/she trained?" If the answer to Question 1 is no, Question 9 should be asked ("was the worker assigned by his/her superior to carry out this task?") which may lead to an end result either of a violation or of absence of operator error.
When the answer to question 1 is yes, Question 2 should be asked to check if the procedure and/or training were adequate and applicable for the task during which the accident occurred. If they are not adequate and applicable, the algorithm indicates that the final answer should be there was "no worker error." On the other hand, if the answer is yes, Question 3 should be asked: "was the procedure and/or training followed?" This question opens up two main branches in the algorithm. If the answer is positive, it should be asked if there was a technical failure (Question 4), which, if confirmed, indicates that there was no operator error. If a technical fault did not occur, the question should be posed of whether the problem occurred in the context of an unforeseen situation (Question 5). If it was unforeseen, it is characterized as an error that occurred when the worker was operating at the level of knowledge (KB error). If a routine situation, it is characterized as a slip.

As to a negative answer to Question 3, this opens a new line of questioning that begins with Question 6 ("if the procedure and/or training had been followed, would the incident happen?"). If the answer is positive, this indicates that the causes of the event were not linked either to the quality of the procedures or to compliance with them, which leads to the answer "no worker error." Should the answer be no, Question 7 should be asked, which Reason (1997) deems as a substitution test ("would
another worker behave the same way in a same situation?"). If the conclusion is that other workers would act in the same way, the algorithm indicates that there was "no worker error."

Should the answer be no, Question 8 should be asked ("was the error intentional?"). If the behaviour was not intentional, it is characterised as a memory lapse. Otherwise, it is characterised as a violation. It is worth emphasizing that, after obtaining the conclusion about which type of error occurred, or obtaining the conclusion that no error occurred, the last question of the algorithm should always be asked ("was there any other worker involved?"). This question was introduced to emphasize that the algorithm should be applied to everyone who formed part of the team of operators involved at the scene of the accident, rather than just the victim.

It is also worth stressing that the result “no worker error” means that there was no error of front-line workers. Indeed, in such cases there may have been an error by someone else (e.g. management).

4. Research method

In order to identify opportunities for improving the algorithm, it was applied in the analysis of accidents that had occurred in a small construction company in Brazil, which dealt with both residential and commercial projects. During the period when this study was conducted, the company employed 70 workers on their construction sites (none of which were contracted out), besides 3 civil engineers and 1 architect. The main criterion for choosing this company was the ease of access that the researchers had to data. HSW management is characterized by the attempt to comply with legislation, with no use being made of any practice linked to excellence in performance in HSW in civil construction, such as those identified by Hinze (2002). The company had no procedure to guide the investigation of accidents, nor were there documented records of accidents that had occurred.

Thus, it was necessary for a member of the research team to visit the company's three construction sites that were in progress during the research study. They asked the 70 employees individually if they had experienced or witnessed an accident at work in the company studied. Based on these questions, 26 accidents were identified. However, only 19 events were selected for inclusion in this study, given that, in the other cases, the workers who had suffered injuries and who, therefore, could have added important information, were no longer employees of the company.

In the next stage of the research, interviews were conducted with the following stakeholders and in the following sequence: (a) with the workers who had been injured, (b) with the workers who were on the team in which the victim had worked, (c) with the company’s three engineers. These interviews aimed to clarify the context in which each event occurred, to underpin the understanding of its causes and to obtain support for applying the algorithm. With regard to the workers (31 interviews in all), the interviews lasted on average for about 30 minutes and were not tape-recorded in order to minimize embarrassment or inhibitions. Interviews with workers were in three stages:

(a) Initially, they were asked to provide information which allowed a basic characterization of their profile and the severity of the event to be made, such as their length of working service in the
company; education; age; position; years the event occurred; length of time they were laid off as a result of the event;

(b) Next, the researcher asked the interviewee to give his version of the accident so as to, based on this, recount the story back to him in order to check if the researcher had correctly understood what had really happened;

(c) In the last stage, questions were asked based on a script drawn up by Dekker (2002) to support the understanding of the organizational context that led to the human errors. This script gave rise to other questions during the interview and included questions such as: has a similar situation happened before? Were you trained to deal with this situation or was it a new or unforeseen situation? What safety rules or work performance rules clearly apply in this work situation? Were these rules followed? Was the task carried out under pressures of time, cost or other such ones? Do you think another colleague would do the same thing you did or would he do it differently?

As to the interviews with the engineers, they were held to clarify technical aspects related to each event, such as checking whether the work performance procedures used at the time of the accident had been the ones usually used in the company. In addition, photographic records were made of the environment in which each event occurred. It should be stressed that the possibility of conducting interviews with the workers and engineers, as well as unrestricted access to the construction sites, allowed the event to be described with a relative wealth of detail, especially in comparison to earlier studies that applied the algorithm, and which were based on the reports at hand in the companies themselves. In general, these reports were superficial.

After the interviews, a detailed description of each accident was written up and the algorithm was applied from the perspective of each of the workers who had been injured and from the perspective of each team member. However, in this first round of applications, the researchers noted difficulties in interpreting the questions, and sometimes the result was inconsistent with the context of the event. Thus, some modifications were made to the algorithm, such that the results presented in this article reflect how the modified version of the tool was applied.

5. Results

5.1 Recommendations on how to apply the algorithm

This item presents recommendations for applying the algorithm which were not explained in the earlier studies. These recommendations are illustrated by drawing on the accidents investigated:

(a) Recommendation 1: before starting to use the algorithm, what should be identified, using the description of the accident, are episodes that may serve as a reference for analysing the types of errors. Such episodes can be both decisions taken by operators and the actions they took. In the field study, the need to adopt this systematic approach became clear in the events in which, in addition to an action having occurred which immediately triggered the accident, the worker, moreover, did not
use the necessary personal protective equipment (PPE). In these situations, the algorithm was applied once more to analyze the action and yet again to analyze the decision not to wear the PPE.

As examples, two similar accidents can be cited in which labourers, not wearing gloves, had had their fingers jammed between the cable of the cart carrying concrete and the door frames. Taking into account the action of pushing the cart which culminated with the impact against the door, the application of the algorithm followed the sequence 1-2-3-4-5-10, which characterises a slip. It is worth mentioning that in Question 3, all that was evaluated was if the proper procedure for pushing the cart had been followed, but what was not assessed was the procedure that required the use of gloves;

(b) Recommendation 2: in case of doubts about the answer to a question, a good practice is to test different alternatives in order to check if the end result will be the same or not. As an example, the case may be cited in which, while a steel bar was being cut in the saw, a spark from the cutting disc hit the eye of the operator, who was wearing safety glasses with side shields. Both using the hypothesis of considering that the procedure was incorrect because the glasses were not of the appropriate model (sequence 1-2-10), and using the hypothesis of considering that the glasses were adequate, but perhaps they were damaged (sequence 1-2-3-4-10), the conclusions are that there was no error by the worker;

(c) Recommendation 3: based on recommendation 1, we see that it is possible, even without the application of the algorithm, to conclude that there was no error by the workers involved. Such cases include situations in which there was no action or decision by the workers who serve as references for the application of the algorithm. For example, mention may be made of the accident in which the shoring of a foundation trench did not support the loads and a worker was partially buried. In this case, although the application of the algorithm was unnecessary, it was nevertheless used (sequence 1-2-3-4-10) in order to validate it for such scenarios;

(d) Recommendation 4: the implementation of the algorithm should be undertaken by a team and include the participation of members with experience of the domain in question. In fact, two of the three authors of this study are civil engineers, one of whom is also an engineer of the company investigated, which facilitated understanding the events, their causes and corrective actions.

5.2 Modifications in the algorithm and recommendations as to interpreting the questions

This item presents seven modifications or recommendations for interpreting the questions of the algorithm, mainly targeting its being adapted to the context of construction sites:

(a) Modification or recommendation 1: the interpretation of Question 2 ("was the procedure and/or training adequate and applicable?") can be difficult when there are no documented procedures that specify the steps and rules applicable to the task, as was the case in the construction company investigated. In this case, it is proposed that the procedure adopted as a reference should be the one described in regulations or the one that is tacitly accepted as correct by workers and managers.
If it becomes evident from interviews that there is no consensus about what the procedure tacitly accepted as correct is, the answer to Question 2 should be no. This situation can be illustrated by an accident while the tower of the hoist was being dismounted. In that incident, a worker who was inside the building receiving the elements of the tower (each with a size of 1m x 2 m) broke a finger when his hand was squashed between the piece being received and the structure of the tower. The sequence in the algorithm of the investigation was 1-2-10, for all team members, making it clear that the procedure was inadequate. In fact, there was no consensus either about how many people should remove the pieces, or about whether or not to use gloves for this task, or about what the responsibilities of the employees involved should be. Although there is an intrinsic risk of something falling from a height in this task, it is likely that the lack of consensus arises from the fact that this operation is usually performed only once during the life-cycle of a construction site;

(b) Modification or recommendation 2: since the previous proposal is taken into account, it is unnecessary to make mention of the word training in Questions 2, 3 and 6. If the word ‘procedure’ incorporates those that are tacit, this implies that it also covers situations where the operator knows the procedures only through training, whether these are formal or informal occasions based on learning from more experienced colleagues;

(c) Modification or recommendation 3: Question 1 ("was the worker aware of the procedures content and/or was he/she trained?") was difficult to interpret when there were no documented procedures and when the term ‘procedure’ was interpreted according to proposal (a) as put forward above. Thus, it is proposed that Question 1 be replaced with the following question: was it a routine and/or habitual task for the worker? As an example of using this question, an accident can be cited in which a worker, without protective goggles, was splashed in the eye with concrete while it was being poured. Although he did not know the ideal procedure for this situation (wearing glasses), nor had received formal training to do so, the activity was routine. Thus, in this case, the answer to Question 1 was yes.

It is worth mentioning that in the version of the algorithm shown in Figure 1, the researcher could be induced to give a negative answer to Question 1. This would imply the assumption of an improper job assignment for that specific worker, which does not match the context of the example cited;

(d) Modification or recommendation 4: it is proposed that in Question 6 ("if the procedure and/or training had been followed, would the incident happen?") be added the expression “with the same severity”. The need for this change is illustrated by analysing the decision not to wear gloves in the accidents already commented on, and in which the workers had their fingers crushed against the frame of a door when they were pushing a wheelbarrow. If the algorithm were to be used in its original form, this decision would be analysed according to the sequence 1-2-3-6-10 (there was no worker error).

However, although using gloves would not avoid the occurrence of an accident, it is likely their use would minimize its consequences, which is sufficient justification for their use. Thus, according to this proposal, the analysis of the decision not to wear gloves leads the algorithm to the sequence 1-2-3-6-7-8-10 (violation), the option which was considered in the tabulation of the results. These
accidents also indicated, as an opportunity for improvement, that the design of the carts should be re-assessed in order to facilitate their passage through the doors.

(e) Modification or recommendation 5: Question 3 ("was the procedure and/or training followed?") should be answered from the perspective of everyone involved in the team who performed the task, rather than just in terms of the worker to whom the algorithm is being applied. This means that, should any member of the team not have followed the procedure, the answer to Question 3 should be no. Two similar incidents illustrate the need for this recommendation. They involve events in which workers had their feet pierced by nails that were protruding from pieces of wood scattered on the floor. If the proposed recommendation is adopted, the sequence of applying the algorithm is 1-2-3-6-7-10 (there was no worker error), given that other team members did not follow the procedure of removing the nails from the bits of wood and storing them in piles, in an organized manner;

(f) Modification or recommendation 6: the case study indicated that Question 7 ("would another worker behave in the same way in the same situation?") remains subjective even when it is possible to compare a worker’s performance with that of his teammates. In fact, when there is a team involved, subjectivity still persists to the extent that the performance of different teams should be compared to it. Thus, it is proposed that, if in doubt, a supporting question be used as a subsidiary one in order to answer Question 7 (it is suggested that this question should not be included in the graphical representation of the algorithm): were resources for applying the procedure available, without there being any dependence on others? This question aims to make explicit one of the main reasons that can lead to the breach of an ostensibly proper procedure, namely the lack of the resources (e.g. material or human resources) needed to apply it. If the answer is yes (the resources were available), this probably means that other workers would not act in the same way. If the answer is no, this probably indicates that other workers would act in the same way, thus characterizing the absence of error.

Four examples are cited which justify the contribution of the support question, it being the case that the first two resulted in violations and the last two in the absence of error. The first example refers to an accident during the transport of steel bars by three workers. During loading, the bundle of bars spilled open and a worker had his hand squashed between the irons. However, this worker was the only one of the three who was not wearing leather safety gloves, which, according to the investigation were available. Therefore, given his decision not to wear gloves, the application of the algorithm for the injured worker had the sequence 1-2-3-6-7-8-10 (violation).

As to the second example, unlike the previous one, this illustrates a situation in which all team members acted in the same way. In this case, three workers were preparing a cement mixer to be manhandled over a short distance, without having set a safety lever that would have maintained its loader fixed on top of the mixer. However, one of the team members crossed in front of the mixer (the tacit rule was always to cross behind the mixer, since the loader could only fall forwards) at the same moment as the loader fell, hitting him in the back. In this case, the resources to perform the correct action were available (the lever was in good condition and was accessible) and the application of the rule was immediate, depending only on the workers' action. In applying the algorithm, the decision not to set the safety lever was counted as three violations, one for each team member.
Nevertheless, other accidents revealed situations in which resources were not available and the procedure was not easy to apply. In one such case, the worker used a portable ladder as a support to nail the mould for a beam, and probably due to losing his balance, fractured his finger after hitting it with a hammer. In another case, in order to get down from a suspended scaffold, a worker jumped from a height of 1.50 m to reach the ground, lost his balance and broke an arm. In both accidents, the algorithm indicated the sequence 1-2-3-6-7-10 (there was no error). In fact, the procedures set out in Brazilian regulations and good practices in the industry recommend the use of scaffolding as a means to get access to the beams and to use a ladder to descend from scaffolding. However, such resources (scaffold and ladder) were not made available, which made the choices the workers made necessary and regarded as normal.

**Modification or recommendation 7:** the original version of Question 8 ("was the error intentional?") was replaced with the following one: was the action and/or decision intentional? The purpose of this change is to make explicit the concept of error presented in item 2 of this article.

If all the proposals presented are taken into consideration, one can arrive at a new version of the algorithm which is appropriate for the context of construction sites (Figure 2).

![New version of the algorithm](image)

Figure 2: New version of the algorithm - shadowing highlights changes in comparison with the version presented in Figure 1.
5.3 Error types in the accidents investigated

The 19 accidents investigated made it possible to apply the algorithm 34 times, with 22 of these applications referring to the points of view of the workers who had been injured and 12 referring to those of their team-mates. From the perspective of those who had been injured, the number of applications of the algorithm was greater than the number of workers involved. In fact, whereas 19 workers had been injured, the algorithm was applied 22 times to them, given that, in some events, there was more than one action or decision that served as a reference for the application. Table 1 summarizes the types of errors for all the workers, only for those injured and only for their team-mates.

Table 1: Error types in the accidents investigated at construction sites

<table>
<thead>
<tr>
<th></th>
<th>Applications for all the workers (n = 34)</th>
<th>Applications for the workers injured (n = 22)</th>
<th>Applications for their team-mates (n = 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>There was no error</td>
<td>24 (70.5%)</td>
<td>15 (68.2%)</td>
<td>9 (75%)</td>
</tr>
<tr>
<td>Violations</td>
<td>8 (23.5%)</td>
<td>5 (22.7%)</td>
<td>3 (25%)</td>
</tr>
<tr>
<td>Slips</td>
<td>2 (5.9%)</td>
<td>2 (9.1%)</td>
<td>0 (0.0%)</td>
</tr>
</tbody>
</table>

Based on Table 1, it can be seen that, whatever the perspective, the category of “no worker error” was predominant. In particular, team-mates played a passive and reactive role in most events. Although they committed only 3 violations, they did not contribute to warning colleagues of the hazards. Such data may indicate that teams lack skills in perceiving risk, of communication and of coordination, which are not normally emphasized in the training of construction workers. It is also important to note that two categories of errors were not associated with any application of the algorithm. Regarding the absence of errors at the level of knowledge, this is compatible with the nature of the tasks performed on the building sites of the company investigated, such tasks being relatively repetitive and predictable. On the other hand, these kinds of tasks are susceptible to memory lapses, especially in dynamic environments such as building sites, where there tend to be several interruptions in routine activities that give rise to lapses. The absence of lapses can mean either that their consequences have not been strong enough to contribute to an accident, so much so that such errors are difficult to identify because they generally lead to the omission of some activity, which in turn makes it difficult to observe the error.

Considering the results of table 1, in the context of the construction company investigated, there is evidence that the greatest potential for advances in HSW lies in tackling latent conditions rather than active failures of workers. In fact, this indicates that regardless of being a human error investigation tool, the proposed algorithm does not adopt a person model of accident causation (Reason, 2008). It induces the investigation of the context in which errors happened (a feature of system models of accident causation) which allow the identification of contributing factors that are temporally and physically distant from the accident scenario.
6. Conclusions

The main objective of this study was to identify opportunities for enhancing an algorithm for classifying types of human errors, based on its application to the investigation of accidents on building sites. Thus, this study resulted in a new version of the algorithm, adapted to the context of building sites. The need for this new version arose from the difficulties of interpreting the questions in an environment that did not possess formal procedures and in which the breach of good HSW practices appeared to be the rule. It is worth stressing the fact that 70.5% of the applications have indicated the absence of error is strongly indicative that HSW actions should be primarily targeted on the management of the enterprise, rather than being focused on the behaviours of the workers.

References


