SAFETY AT WORK: A COMPLEX OR AN EXCEEDINGLY SIMPLE MATTER?

Rodrigo F. S. Gomes*[1], Leandro Gauss[2], Fabio Sartori Piran[3], Daniel Pacheco Lacerda[4]

•

[1, 2, 3, 4]PPGEPS/GMAP. Graduate Program in Production & System Engineering. Universidade do Vale do Rio dos Sinos, São Leopoldo/RS – Brazil.

E-mail: [1]rodrigofrank@edu.unisinos.br, [2]lgauss@unisinos.br, [3]fpiran@unisinos.br, [4]dlacerda@unisinos.br

* Corresponding author

Abstract

This paper uses the concept of inherent simplicity stemming from the Theory of Constraints to explain whether safety at work is a complex or an exceedingly simple matter. In this context, the study seeks to explore the causalities that govern safety at work, identifying its constructs and presenting logic propositions based on the theory-building blocks: classification, correlation, and causal consistency. To support the research, a dataset composed of 46 work-related accident investigation reports from an elevator industry in Latin America was carefully analyzed using association rules. Moreover, direct observations grounded on inductive reasoning were used to speculate plausive causes concerning the effect of work-related accidents. The research strategy followed common strategies of theory building to reach common sense: theory-to-practice and practice-to-theory. As a result, a conceptual proposition is postulated based on the reasoning that safety at work is governed by very few constructs, and that its complexity is explained through the two elements from inherent simplicity: degrees of freedom (interdependencies between constructs) and harmony (conflicts resolution within the work environment). From the practitioners' perspective, the study also offers directions towards safety improvements at the organizational level by considering the impact of the interdependencies between constructs in safety at work.

Keywords: Inherent simplicity. Safety at work. Theory of constraints. Theory building. Causation

I. Introduction

The field of safety science is advancing very slowly, despite an increasing volume of research activity and publication [1]. On one side, a massive body of knowledge is available in literature in a form of cases, frameworks, mathematical models, and systematic literature reviews. On the other side, practitioners are struggling to improve safety practices within organizations without considering theories and published shreds of evidence. While this disharmony between theory and practice in safety science is verified, society remains to deal with social and economic impacts arising from ineffective safety management.

According to ILO [2], more than 2.8 million deaths per year result from occupational accidents or work-related diseases. When considering non-fatal work-related injuries, this number increases to approximately 376.8 million a year. Moreover, the burden resulting from such ineffective safety management accounts for economic losses estimated at 3.94% of the global Gross Domestic Product [3–5].

This pragmatic reality shall draw the attention of researchers and practitioners due to its impact on society. This is because a healthy and safe work environment not only is desirable from the workers' perspective but also contributes considerably to labor productivity and promotes economic growth [6]. Furthermore, safety at work promotes worker motivation, increases productivity by reducing costs related to work-related health problems, and relieves pressure on public and private health systems.

Based on such a challenging scenario, a step back seems to be necessary. Rather than propose solutions to address just a piece of this issue, it is necessary to make sure that safety at work is well understood in academia and within organizations.

In this context, this paper aims at identifying the constructs and presenting propositions to explain the causalities that govern safety at work. In addition, this study explores how the definition of complexity should be understood in the field of safety science, and what is the prevailing definition. This is fundamental to draw attention to the main factors that affect safety, and how their interdependencies might increase or decrease the complexity of the system.

In that reasoning, the theoretical discussion of this study is structured on building blocks proposed by Whetten [9], and consistent with the three stages of science proposed by Goldratt [10]: classification, correlation, and causation consistency. As a major theoretical outcome of this research, the causalities that govern safety at work and its complexity are explained through the two elements of inherent simplicity: degrees of freedom (interdependencies between constructs) and harmony (determined by the belief that every internal conflict can be removed by eliminating improper assumptions).

From a managerial's perspective, this study is useful for practitioners to put efforts on critical constructs that impact the overall safety management system to make it simpler and harmonious, instead of acting to reach local optima.

Finally, this study also has a side contribution in extending the applications of Theory of Constraints (TOC) to the field of safety. Since literature is particularly lacking in investigative studies on the theoretical and practical implications of TOC principles [11], this research contributes to closing this gap since no previous study is found connecting inherent simplicity and safety science.

This article is organized as follows: Section II outlines a comprehensive review of the concept of inherent simplicity. The work method is described in Section III. In Section IV the results are presented and a narrative of theoretical discussion is conducted. Finally, the main conclusions and limitations of the study are summarized in Section V.

II. Inherent simplicity

The concept of inherent simplicity is a principle from the Theory of Constraints [10] in which is postulated that any part of reality is governed by very few elements and that any conflict can be eliminated [12]. In its earliest stage, TOC focused on production system optimization before being recognized as an operations management theory to foster the process of ongoing improvement. Further on, TOC became a global management philosophy applied to various areas such as production, supply chain, project, and other fields [11]. In the theoretical field, TOC also satisfies the virtues of a good theory, such as uniqueness, parsimony, and generalizability [13].

Goldratt [10] outlined that TOC is grounded in its practicability, and unlike in common sense, "theory in science must be practical, otherwise, it is not theory but just an empty scholastic speculation" (p.32). This is consistent with the assumption that the purpose of good theory shouldn't be other than describe and explain how things actually work, and in so doing to help us improve our actions in this world [14].

The concept of inherent simplicity can also be understood as a practical way of viewing reality. However, reality usually looks complex to us, and Goldratt took for granted the foundation of modern science from Newton: "*Natura valde simplex est et sibi consona*" (nature is exceedingly simple and harmonious with itself). It does mean that if we deep dive enough into observing phenomena, we'll find that there are very few elements at the base that govern the whole system. Reality is, therefore, built in wonderful simplicity [12].

The interpretation of Goldratt from Newton's quote is also consistent with the principle of bounded rationality (Simon, 1957, pp. 198-199): "the capacity of the human mind for formulating and solving complex problems is very small compared with the size of the problems whose solution is required for objectively rational behavior in the real world". In other terms, the key to simplification of the choice process is rather the goal of "maximizing", the goal of "satisfying", i.e. finding a course of action is good enough". This association of concepts was postulate by Eden and Ronen [8] and in-deep described by Naor et al. [13] for further readings.

The prevailing definition of complexity is that the more entities the system has, the more complex the system is. Thus, by following this approach to compare the complexity of the systems 'A' and 'B' represented in Figure 1, the system 'B' is more complex than 'A' because the quantity of entities that comprise the system 'B' is higher than 'A'. However, since we are more interested in understanding, predicting, and controlling the system instead of just describing it, this study follows Goldratt's approach to define complexity by the following: the more degrees of freedom the system has, the more complex it is [12].

The concept of degrees of freedom might be clear for physicists or engineers but it is not under overall comprehension. In short, Goldratt explains that it means the minimum number of points (or entities) you have to touch in order to impact the whole system. For example, in the case of system 'B', by impacting the bottom circle, the whole system is impacted, i.e. it has only one degree of freedom. On the other hand, system 'A' has five degrees of freedom, which is harder to control and predict due to its magnitude. This becomes clear by observing the absence of arrows in the system, which means that there are no interdependencies between the entities. Figure 1 illustrates the reasoning of complexity based on inherent simplicity.

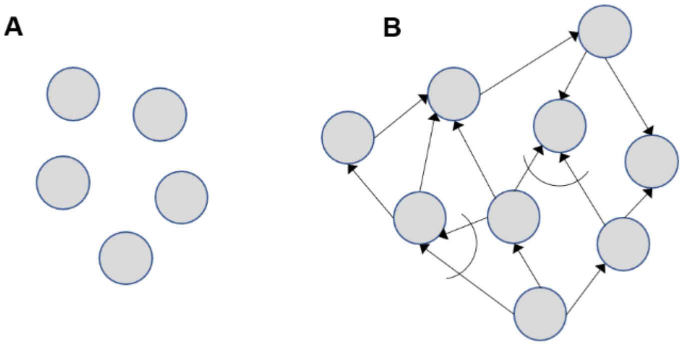

Figure 1 – *The reasoning of complexity* [12]

Safety at work also might look complex to researchers and practitioners. One possible reason for that is the lack of comprehension about what plausive constructs govern this phenomenon, and how these constructs are interconnected to define the degrees of freedom that govern the system. Seeking the same logic applied to safety science, if the constructs that govern safety at work are identified, and the propositions between them are clear, it is possible to decipher the level of complexity of this matter.

III. Research Design

This study is based on 18 months of direct observations and primary data analysis concerning investigation reports of work-related accidents occurred in an elevator industry. The industry's activities are spread out over 12 countries across Latin America, covering one industrial facility in Brazil and more than 75 service operating units across the region. During this period, the first researcher had close contact with a reality-based source of data, in which scope it is included both manufacturing and service areas in the twelve countries where the organization has an operational presence.

The work method used both common strategies of theory building: theory-to-practice and practice-to-theory [7, 14] as shown in Figure 2.

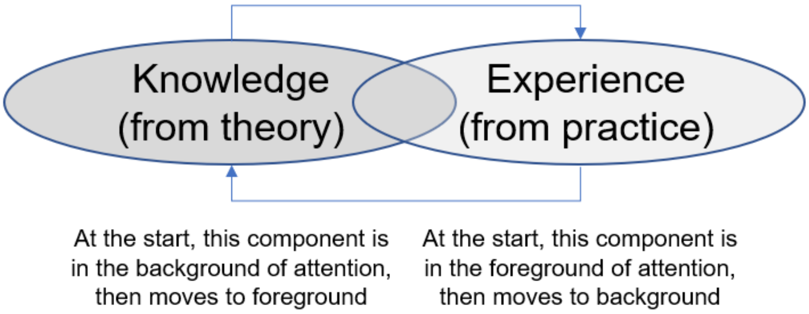

Figure 2 – *General method of theory building in applied disciplines. Source: Adapted from Lynham (2002)* [14]

Initially, the researchers observed an effect: the occurrence of work-related accidents as an issue with significant social and economic impacts worldwide. Then, following the stages proposed by Goldratt [10], the focus moved to speculate plausive causes to explain this phenomenon. To do that, a research question was therefore defined, and awareness about the research problem was sought based on specialized literature.

The next step accounted for the use of a theory-to-practice approach to assume that very few constructs govern safety at work. In that reasoning, the principle of inherent simplicity derived from TOC was reviewed and the theory was framed in the field of safety. As a second stream, the research moved on to the practice-to-theory approach through reality-based data collection to analyze and come up with theoretical and practical contributions to safety science, exploring how and why the constructs that govern safety at work are interconnected and seeking to uncover underlying issues to explain its complexity. A detailed step-by-step of the work method is depicted in Figure 3.

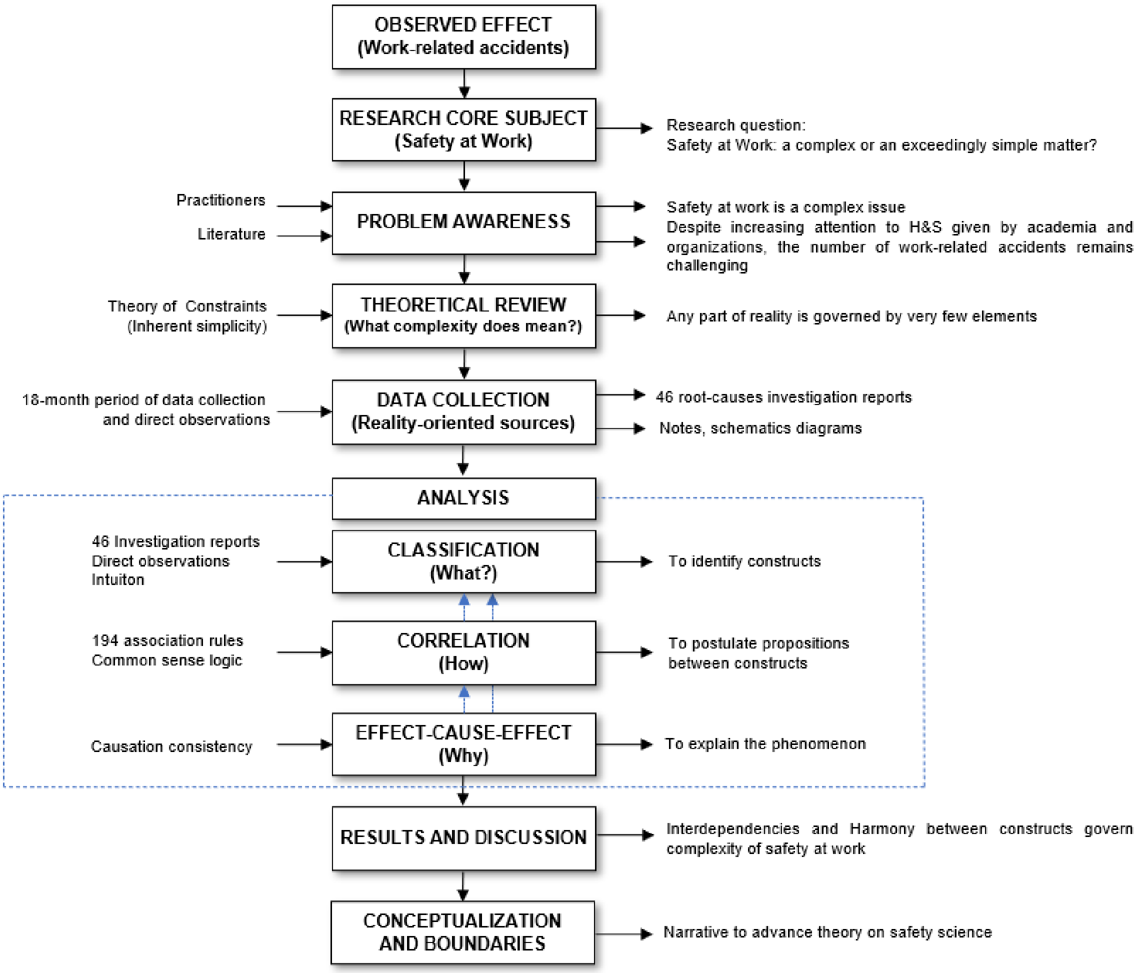

Figure 3 – *Core research subject*

The first researcher examined in depth the existing body of documents in the occupational health and safety management system (OHSMS), the structural functioning of the case unit, and how health and safety (H&S) fits into the organization's strategic planning. Also, several job site visits were conducted to observe how the work is done, the resources available, level of technical knowledge, procedures, routine instructions, task planning, and personal protective equipment (PPE) usage.

Data retrieved from the OHSMS was studied through a business intelligence (B.I.) dashboard covering the period between oct-19 to mar-21. Forty-six root-causes investigation reports listed in Table 1 were collected and analyzed with the support of three specialists. The specialists are H&S managers in charge of the three main operations within the organization: the factory located in Brazil, field operations in Brazil, and field operations in other Latin American countries. In addition, an organizational psychologist supported the discussion when behavioral aspects were reported as contributive causes to the accidents.

Table 1 – *Root-causes investigation reports*

Country	Working hours	Root-causes investigation reports derived from lost-time accidents	
		Factory	Services
Argentina	403,000	-	1
Brazil	14,000,000	1	28
Chile	1,387,000	-	4
Colombia	1,256,000	-	2
Costa Rica	91,000	-	1
Mexico	978,000	-	3
Panama	2,918,000	-	2
Paraguay	372,000	-	1
Peru	1,049,000	-	1
Uruguay	163,000	-	2

Each root-cause investigation report followed a structured template based on 9 categories and 41 data fields (see appendix A 1). The outcome of this analysis was to identify and classify the most frequent factors that impacted work-related accidents.

Moreover, a data mining through the algorithm *Apriori* was powered to identify association rules between factors, i.e., what antecedent factors (named *lhs*) impact the other consequent ones (named *rhs*), and how strong is this correlation. It consists of a data mining algorithm that systematically controls the exponential growth of candidate itemsets [16]. The parameters support (supp=0.5), and confidence (conf=0.8) were set up as thresholds based on adopted criteria from previous studies [17, 18].

The parameter support determines how often a rule applies to a given dataset. Besides, it aims to identify the most relevant rules [20] in the dataset. Confidence, in turn, determines how frequently consequent factors [*rhs*] appear in relationships that contain antecedents [*lhs*]. It is used to measure the strength of an association rule, expressed as the times a specific itemset is found together with a specific item out of the total times this specific itemset is found in the entire dataset [18]. In other words, the greater confidence of rule $\{X\} \Rightarrow \{Y\}$, the greater the probability of $\{Y\}$ being present in events that contain $\{X\}$ [21].

An additional measure used in that research is the 'lift'. The lift of an association rule is responsible for measuring the difference between the number of times $\{X\}$ and $\{Y\}$ co-occur and the expected frequency of such co-occurrence if they were statistically independent [22]. In that reasoning, high levels of lift mean that the consequent factor is scarcer within the population and more frequent within the specific itemset.

For this step, a script loaded in software RStudio was used for data processing (see appendix A 2). Additional explanations about the use of association rules can be found in the work of Zhang and Zhang [16] and other mentioned literature. Furthermore, examples of how to explore cause-effect relationships using association rules in the H&S field can be found in the studies of Cheng et al. [23], Mirabadi and Sharifian [24], and Verma et al. [25].

Through this technique, 194 associated rules were retrieved to support the correlation stage. The structure of rules is presented in Table 2 and can be interpreted as follows: based on a dataset with N events, the rule [n1], for example, associates the antecedent factor A to the consequent factor C. The support of this rule can vary between 0 – 1. A minimum support threshold is used to select the most frequent (and hopefully important) factors' combinations. Confidence, similarly, is understood as an estimate of the conditional probability of factors co-occur in a rule (0 – 1).

Finally, the lift value of 1 indicates that the factors are co-occurring in the database as expected under independence. Values greater than 1 indicate that the items are associated, and lower than 1 indicate an absence of association [22].

Table 2 – *Structure of association rules*

Rule	lhs		rhs	support	confidence	lift	count
[n1]	{antecedent A}	=>	{consequent C}	0 - 1	0 - 1	0 - ∞	1 – N
[n2]	{antecedent A, antecedent B}	=>	{consequent D}	0 - 1	0 - 1	0 - ∞	1 – N

Besides the investigation reports, other general documents were carefully analyzed, e.g the strategic planning 2020-2025, OHSMS manual, and H&S policies. From these documents, it was possible to situate expected management commitment as well as H&S in the strategic context of the organization, in order to check against reality through direct observations.

Direct observations were conducted in the course of the same period of the primary data collection. It followed as possible, a semi-structured approach as follows: (1) to verify the work being performed, such as the use of tools and personal protective equipment, printed instructions, work environment, etc; (2) to conduct an informal conversation to understand the task routine, capabilities required to the task, and capacity to foreseeing risks; (3) to verify the leadership commitment from the worker's perspectives, and possible behavioral impacts from externalities, such as COVID-19, personal issues. Yet, the informal approach was given to avoid the feeling of pressure when formal questions for interviews could bring up.

Moreover, additional factors were observed at the job sites beyond the technical field. The education level and behavioral aspects, such as lack of concentration and lack of awareness were considered as well. Also, the observations were not limited to job sites. Management meetings and reactions from the occurrence of accidents were also observed. Preliminary speculations from the direct observations were registered in notes and schematic diagrams to reach common-sense logic. Furthermore, confirmation questions were frequently used at the end of any informal approach: "if I understood well this effect was caused by this fact. Am I right?".

The relevance of the direct observations is based on the fact that it is rarely found whether in literature or in reality-based practices, pieces of evidence related to explain the safe work, i.e. a deep analysis of what went good, and the factors that led to a work environment in which safety culture is intrinsic. As an outcome of the use of both association rules and direct observations, a framework is proposed to explain the causalities that govern safety at work since it allows the researcher to observe, in practice, the effect-cause-effect stage.

Based on the framework elaborated, the first researcher was encouraged to use verbalized intuition with other researchers and practitioners [10] to practice simplicity, parsimony, and to reach common sense.

In that reasoning, principles of causal consistency derived from the Theory of Constraints Thinking Processes were also used to explain each proposition presented in the framework: causality existence, causality clarity, the sufficiency of cause, and additional cause [26]. As a result, a conceptualization of complexity in safety at work is postulated.

In the next session, results are discussed throughout a combined approach of the three main stages that every science has gone through [9, 10]. The classification stage was associated with the ‘what’, correlation with the ‘how’, and effect-cause-effect with the ‘why’. Finally, the researchers sought to define limitations in time and context for the propositions. These contextual factors are critical to set the boundaries of generalizability in which the propositions are postulated.

IV. Results and Discussion

I. Classification (building block ‘what’)

This stage sought to explore what constructs logically impact safety at work. In this context, the criteria of comprehensiveness and parsimony supported the researchers to determine whether a factor should be considered as a variable to explore the causalities of safety at work. In short, it was sought for relevance and value-added of each variable to explain phenomena [9]. One primary instance of identifying these constructs was based on an inductive approach and intuition. Initially, it was considered plausive factors that influence phenomena (safety at work). For instance, technical expertise is a plausive factor to impact positively safety. However, even in case of considering this example a common sense, it does not explain what is its level of importance, how this factor is connected to others, and what is its effect on the whole system.

In addition, the analysis and classification of primary data and the findings obtained through direct observations supported the researchers in that stage. Numerous factors came up with this process, including training, task planning, years of experience, education level, availability of proper tools, personal protective equipment usage, adequate instruction. However, at this point in time, no correlation was checked, and each factor was considered an independent one. In that reasoning, consistent with the concept of inherent simplicity, the system primarily seemed to be very complex (see Figure 4)

Figure 4 – *Factors that impact safety at work*

The next step was to practice simplicity and parsimony, considering that theory should have a minimum of complexity and few assumptions. Each variable was considered as a potential factor to impact safety at work. Next, every variable was associated with a construct as a theoretical element wherein the variable is encompassed. A minimum number of constructs was sought in order to reach simplicity and decrease complexity.

In that reasoning, after the data analysis, an interactive process of verbalizing the factors grouped in constructs with other researchers, H&S experts, and workers was conducted to reach common sense. In this context, variables were grouped into constructs to reach a higher level of abstraction, keeping the properties of comprehensiveness. For instance, variables such as technical training, safety training, hazard analysis were grouped into the construct 'knowledge'. This is because 'knowledge' encompasses several factors associated with the necessity of knowing, for example, 'what to do', 'how to do', 'what are the risks involved, 'how to mitigate the risks'.

As an outcome of this stage, a set of constructs were defined as satisfactory based on the logic of 'good enough' [8] to explore phenomena of interest (see Figure 5). This is because these four theoretical elements (knowledge, planning, behavior, and performance measure) sufficiently encompass in a form of constructs all variables identified in the classification stage.

In the next sub-session, the propositions between how these constructs are connected are outlined.

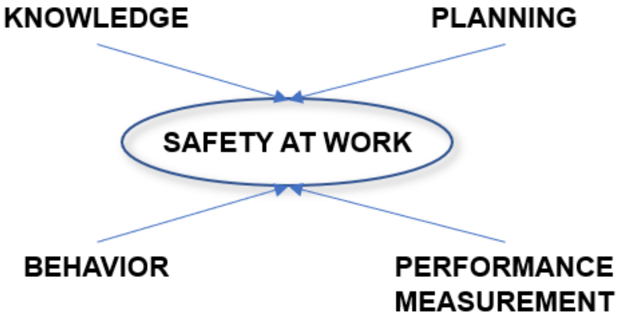

Figure 5 – *Constructs associated with safety at work*

II. Correlation (building block 'how')

Once the minimum necessary constructs to explore phenomena of interest are identified, the next stage aimed to define how they are connected (co-related). Although this stage is based on careful observations and often involves a quantitative approach, the question 'why' is not asked at all. Rather the question 'how' is the center of interest [10]. Based on that reasoning, the propositions were structured with the use of 194 association rules, as shown in Table 3.

Also, the researchers sought to take benefit from the direct observation of works being performed safely. This is because the set of investigation reports analyzed is about 'how things went wrong' (unsafe work). However, seeking for broadening the research perspective, the researchers also focused to verify 'how things go safe' (work safely), to confirm some association rules and intuition.

Table 3 – *Association rules*

Rule	Lhs		rhs	support	confidence	lift	count
[34]	{Inappropriate JHA}	=>	{Lost time Accident}	0.6415	1	1.1522	34
[70]	{Trained to the task}	=>	{Diminishing Risks}	0.6038	0.8889	1.1778	32
[76]	{Trained to the task}	=>	{Lost time Accident}	0.6792	1	1.1522	36
[79]	{Diminishing Risks}	=>	{Daily routine}	0.6415	0.8500	1.1551	34
[100]	{Diminishing Risks}	=>	{Lost time Accident}	0.7547	1	1.1522	40
[145]	{Trained to the task,Working in regular time}	=>	{Unappropriate JHA}	0.5283	0.8000	1.2471	28
[155]	{On-time, Trained to task}	=>	{Diminishing Risks}	0.5283	0.9333	1.2367	28

According to Whetten [9], although the researcher may be unable to test all the links (propositions between constructs), restrictions in methods do not invalidate the inherent causal nature of theory. In this reasoning, and consistent with the understanding that most of what passes for theory in organizational studies consists of approximations [27], the connections and the propositions between constructs are introduced in the framework depicted in Figure 6.

The framework is comprised of fours constructs, and it should be read as the following narrative: knowledge is the starting point. It is represented by work elements such as 'what to do', how to do', 'what are the risks' and 'how to eliminate/neutralize/mitigate the risks'. Knowledge is a construct presented in every type of work. This is consistent with the investigation reports analyzed and coherent with the direct observations conducted throughout the research. In both situations of work safely or work unsafely, knowledge (or the lack of knowledge) is present as a plausive construct that partially governs and explains phenomena of interest. In the case of safety at work, it also represents a baseline since common sense is that knowledge is critical for working safely.

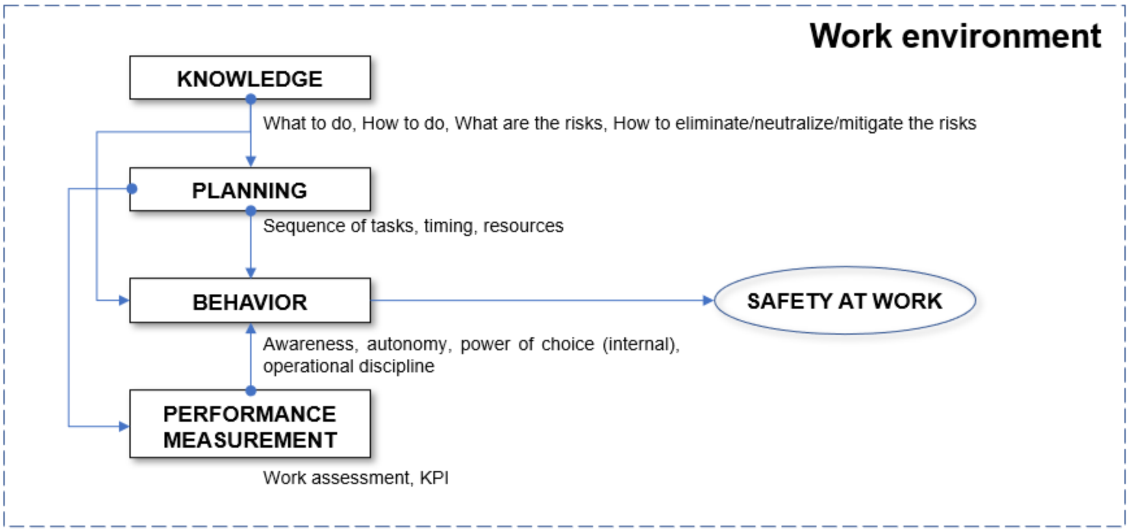

Figure 6 – *Propositions that govern safety at work*

However, knowledge is necessary but far away as sufficient to explain phenomena safety at work. This is consistent with the association rules, e.g. rules [70, 76, 155]. According to those rules, even workers trained to perform their tasks can get involved in lost-time accidents. This association is highly represented in rule [76], in which 36 out of 46 investigation reports analyzed, the worker was trained to the task in question (confidence =1; lift = 1.1522). Moreover, our

observations confirmed that trained workers might diminish risks due to possible reasons, such as their work experience or due to the fact they never had a work-related accident before. Thus, other plausive constructs are necessary to explain what governs safety at work.
Knowledge is connected to construct planning. This reasoning is explained by conceptualizing planning as the way the work is expected to be done, in which sequence of tasks, timing, and with what resources. Following this logic, it sounds clear that 'to plan' depends on 'to know'. By defining a good sequence of tasks, a standard operational procedure, or an estimation for a set of tasks to be completed, it is fundamental to know what is this activity about, how the activities are performed, and what resources are available. Planning also represents the way of performing a task. Well-defined tasks are the ones where the resources, timing, and logical sequence of each activity are established to raise productivity without taking out safety is a core aspect.

The question to be responded at this point in time is whether knowledge and planning are sufficient to defining the minimum constructs that govern safety at work. If so, an expert performing a well-planned task would be ever working safely. Our intuition indicates not, and also the association rules, e.g. rules [34, 59, 145] in which confidence and lift present a high level. Firstly (rule [34]), the lack of operational discipline in doing job hazard analysis (JHA) is associated with trained works. It means that even experts do not follow the planning. Second (rule [59]), resources such as personal protective equipment do not guarantee safety at work. Investigation reports indicated that very often accidents occur with employees equipped with PPEs. This suggests such a level of personal confidence that nothing wrong can happen, and risks are ignored. Finally (rule [145]), diminishing risk is highly associated with lost time accidents, and therefore, the behavioral aspect is another plausive construct to be considered.

In this context, behavior is a comprehensive construct. It is present in the literature in numerous studies about accident prevention, such as in the studies of Han et al. [28] and Li et al. [29]. Also, motivation and work behavior are present in a robust body of knowledge in social sciences [30]. Consistent with the existing literature, results of the association rules put light on the effects of behavior in the work environment, verified in the consequent factor 'diminishing risks', and based on its high association with lost-time accidents (rule [100]). This comprehensiveness is expressed in the proposed framework through the fact that behavior is the most interconnected construct in the system. All other constructs are connected to it, and it is the only one directly connected to the work.

In that reasoning, both knowledge and planning are connected to construct behavior by one of the two directional flows presented in the framework. Both constructs impact the way a person behaves at work. This was verified through direct observations carefully conducted besides the association rules. For instance, consider a worker performing maintenance services. If he/she lacks the required knowledge about what to do and how to perform a repair, or if the worker does not know the risks associated with the task, a potential risk for an incident to occur is increased as the worker tries to perform the task. Also, if the timing defined for the service is inadequate, or if necessary resources are not available, the worker's behavior is impacted negatively, leading towards the opposite direction of safety at work.

Behavior is, therefore, a key construct in the proposed framework. In the context of this research, it is represented by four elements: awareness, autonomy, power of choice, and operational discipline. Each of these elements plays an important role in safety at work.

Awareness is the state of being conscious of something. More specifically, it is the ability to

directly know and perceive, or to be aware of events. Autonomy, in turn, is a condition of self-government, and that needs to be outlined by managers. It is an important element to neutralize risks arising from externalities.
Next is the power of choice, which means the attitude of using awareness and autonomy to every decision at work. Finally, operational discipline means doing the right thing, the right way, every time. It encompasses the other constructs towards promoting safety at work.

From another direction, behavior is also impacted by another construct, represented by the way workers are measured. The performance measurement did not come up with the analysis of investigation reports. Rather, it emerged through the inductive approach and it is consistent with the theory of constraints. Goldratt [10] pointed out that the way an organization defines its work assessment and KPIs impact how workers behave at all levels. For instance, even in the case of an expert performing a well-planned task, if the KPIs are not consistent with the timing required for the task and with the resources available, the behavior is impacted. This is deeply explained by social cognitive theory (SCT), which explains behavior in organizations in terms of the reciprocal causation among the person, the environment, and the behavior itself [30]. Because of these combined influences, under SCT organizational participants would at the same time be products and producers of their motivation, their respective environments, and their behaviors. In that reasoning, SCT and TOC justify the connection between performance measurement and work behavior.

Finally, performance measurement is also connected with planning. This is because performance assessment is intrinsically related to a comparison between what is realized versus what was planned. Moreover, KPIs and targets are typically defined based on strategic planning and organization capabilities (resources). For instance, the expected sales growth rate of a Retail store is defined in management reviews. The organization may expect more sales if more sellers are working for them, or, in the case of use of technologies to increase sales, e.g. web platforms. Both examples are resources, and resources are associated with planning.

The four constructs are interconnected in the boundaries of the work environment, as previously depicted in Figure 6. It represents a system to explain what are the constructs that govern safety at work, and how they are connected.

The work environment is characterized by both external (e.g. market regulations) and internal (organizational culture) existing factors in any work environment that might impact positively or negatively any construct. It plays a critical role for safety at work since it acts directly in promoting (dis)harmony between the connections, and therefore, affects the level of complexity as further explained in sub-session IV.

Internal consistency and parsimony were sought to sustain every proposition’s argument. Each construct in the system has a certain number of in-out connections. In this context, behavior represents the central construct because it is connected with all constructs and it is directly connected with phenomena safety at work. It follows the reasoning of considering ‘to behave’ an expression of ‘acting’, such as ‘working’. Therefore, work behavior is positively or negatively impacted by knowledge, planning, and performance measurement, and all framed into the work environment.

The next session seeks for exploring the causation consistency.

III. Effect-cause-effect (building block 'why')

The previous sections were extremely helpful. 'What' and 'How' provide a framework for interpreting patterns in empirical observations [9]. However, only 'why' explains phenomena.

Existing literature in the field of safety science often lacks explaining causation, being limited to verified correlations. The inherent limitation of any correlation, e.g. findings from association rules, is the lack of understanding of the cause-and-effect relationships between the propositions [10]. After identifying the constructs and exploring the reasoning of how they are connected, the next stage accounted for asking the question why?. In other words, the researchers are focused on what might be causing the existence of each proposition to explain safety at work as the effect of interest.

This stage is aimed no longer just to observe what already exists to explain phenomena, but also to use logical derivations based on existing causes to uncover underlying issues and predict the outcome of entirely new situations. Moreover, this stage accounts for fulfilling the minimum requirements of the conceptualization phase of theory building [7].

At this theory-development stage, logic replaces data as the basis for evaluation [9]. This is consistent with the use of common sense proposed by Goldratt [10] to go through the effect-case-effect stage. Goldratt outlines that it represents the third stage of science, and the most important one because only at this stage there is a widely accepted recognition that the subject is actually a theory-building.

Therefore, the starting point of this stage is to become aware of an effect. The 'effect' of interest in this research is 'safety at work', and in the context of this study, safety at work means the action of working safely. "One effect is enough", said Dr. Goldratt, and the effect comes together with a challenging question: Is 'safety at work' a complex or exceedingly simple matter?

Once the effect and a challenging question are defined, more information is not much needed. Rather, to think and to speculate of plausive causes grounded in common sense are the next step [7, 10, 12]. To do that, principles of causation consistency derived from the theory of constraints thinking processes are applied for each proposition: causality existence, causality clarity, the sufficiency of cause, and additional cause [26]. In that reasoning, the causal consistencies are presented in 5 through a narrative for each connection, and thus, the framework is translated into confirmable propositions or knowledge claims to an explicit connection between the conceptualization phase and practice [31].

Table 4 – *Causation consistency*

Connection	**Causal consistency**
Knowledge → Planning	Knowledge is presented in every type of work. In the context of safety at work, it is a baseline. Knowledge impacts planning because 'to plan' any activity requires knowledge about the nature of the work to be performed. Causal existence is evidenced by examples to sustain that this connection is always the case. For instance, to plan the construction of a house, a common sense is that a body of knowledge is necessary, e.g. what raw materials are required, the method of how to do it, the sequence of tasks, the risks involved in the work, and what other resources are needed. This reasoning is applied to construction but also any other type of work. Planning might be also be impacted by the work environment, in which the proposed framework is represented by the boundary via dashed line (see Figure 6). This is because both external (e.g. macroeconomy, market regulations) and internal factors (organizational culture) existing in any work environment might positively or negatively any construct.
Knowledge and Planning → Behavior	Knowledge and planning are necessary but not sufficient to explain safety at work. Even experts performing well-planned tasks might work unsafely. A common sense to explain why knowledge and planning are not enough is to consider the behavior at work. If a worker behaves diminishing risks or if presents a lack of awareness, the knowledge and planning will not be sufficient at all. Therefore, by common sense, behavior is another necessary construct to explain the phenomena of interest. However, it is still needed to explain the causal existence of this proposition. It is assumed the way a worker behaves performing a task is impacted by his/her knowledge and how well the task was planned. This logic is explained also by examining accidents associated with knowledge in two ways: (1) the worker with the proper knowledge to perform a task and the one with a lack of knowledge to do so. In the first case, the proper knowledge can lead the worker to behave and work safely, but also an excess of confidence can lead to failures in following safety procedures. In the second case, the lack of necessary knowledge can lead the worker to unconsciously put himself/herself at risk. The same reasoning is applied to planning. If the sequence of tasks is carefully designed, proper resources are available, and timing is adequate for the task (a general harmony), the worker with autonomy and power of choice is predicted to work safely. This explanation put light on the causal existence and clarity of this proposition. However, sufficiency is not reached yet. There is speculation that people within the organizations are responsive to the way they are measured. By considering it as a plausive, relevant, and necessary construct to explain the complexity of safety at work, performance measurement (as a construct) was added to the framework.
Planning → Performance Measurement	Performance measurement is connected by planning. This connection is intrinsically observed in management reviews and strategic planning. The definition of key performance indicators (KPIs) considers the organization's planning because it takes into account capabilities, resources, timing, and the work environment influences. For instance, typical planning for the construction of vertical buildings in Brazil varies between 36 and 48 months. This general planning cascades several other

Connection	Causal consistency
	sub-plannings to define all that is needed to accomplish each phase of the project. KPIs for each phase and each task are also defined. Therefore, clarity and the existence of causation between planning and performance are verified. Another way to reach common sense that performance measurement is impacted by planning is by exploring the main KPIs of an industry. Productivity, for instance, is a performance measure that considers the ratio outputs/inputs. To increase productivity, practitioners evaluate how the activity is planned to be performed, including resources usage, quality of processes, and lead times. Following that reasoning, a KPI defined without taking into account planning sounds like no sense.
Performance Measurement → Behavior	Within organizations “people behave under influence of how they are measured”. This quote retrieved from principles of the theory of constraints [10] is consistent with the existing literature about social cognitive theory (SCT) which explains behavior in organizations in terms of the reciprocal causation among the person, the environment, and the behavior itself [30]. It is important to highlight that behavior is the most interconnected construct in the proposed framework. Based on both theories it is assumed that the way a worker behaves at work is impacted by how the performance is measured, and also by his knowledge and how well is the planning of the task to be performed. Clarity of this proposition can be reached by examining productivity. For instance, consider a production line used to produce 22 elevators per day (just quantity). This level of productivity is consistent with the resources available (machinery, personnel, and tooling), and all workers are focused only on pushing forward the production line to reach the target. However, based on some organizational changes and observing that the production was also full of wastes, managers decide to consider efficiency instead of production volume as the performance measurement. Then, workers start to carefully look after the inputs to avoid any waste to maximize efficiency. This example comes up with pieces of evidence of why performance measurement impacts behavior. In this logic, The behavior characterized by a higher level of attention to avoid wastes was influenced by the changes in the performance measure.
Behavior → Safety at work	Finally, behavior is directed connected to safety at work, because in the context of this research it means the phenomena of working safely (co-existence). In more practical words, the action of working safely. Behavior is, therefore, a key construct in the proposed framework due to its high interconnection with other constructs. Moreover, besides being impacted by knowledge, planning, and performance measurement, it represents the utmost connection to the phenomena, expressed through a few elements such as worker’s awareness, autonomy, power of choice, and operational discipline. The existence of causation between behavior and safety at work is well-known in literature and also between practitioners. This is consistent with the concepts of behavior-based safety (BBS), as well as voluntary safety programs within organizations to raise safety awareness as a tentative to prevent accidents. Each of the mentioned elements of behavior at work plays a critical role in safety at work. In the instance of safety at work, they encompass the action of doing the right thing, the right way, every time.

IV. The complexity of safety at work

A major outcome from the stages of classification, correlation, and causation consistency, is to underlying the issues that govern safety at work, and therefore, its complexity. Through the comprehension about what minimum constructs are sufficient to explain safety at work, how they are connected and why, this research's seed is postulated:

Proposition: The complexity of safety work is a function of the degrees of freedom and harmony between constructs that govern the work environment within an organization.

Every organization has an unique system as depicted in Figure 6, represented by the individual and collective knowledge, the work planning, and the performance measurement system. The way these constructs are connected impacts the behavior of workers, and therefore defines the complexity of safety at work.

Although each connection between constructs has generalizability, which means that it can be verified in every organization, it does not mean it is harmonious. The concept of inherent simplicity is grounded in two main beliefs: simplicity and harmony: Simplicity is expressed by the fact that there are very few elements that govern the whole system. Harmony, in turn, is expressed by considering that any conflict can be eliminated [12].

The framework and propositions depicted in Figure 6 follow the same reasoning that Figure 1(B). It demonstrates that a system to represent safety at work might be exceedingly simple. This is possible since the system is comprised of four interconnected constructs that represent only one degree of freedom. However, this is necessary but not sufficient. The harmony between constructs is also a key factor.

Organizations usually face serious problems to properly address well-defined internal processes, and local optima is preferable instead of thinking as a whole. Moreover, problems arise from conflicts and disharmonies. As a result, organizations increase the number of system's degrees of freedom, fail in eliminating conflicts, and tend to address safety as a very complex matter.

This explains the challenges often faced by larger organizations. For instance, the disconnection between the planning department and the operations (who perform the work) or changes in the performance measurement system without taking into account the resources needed, causes disharmony and adds degrees of freedom to the system. Following the inherent simplicity concept, more points have to be touched by management in that case.

Therefore, we postulate that the complexity of safety at work is based on inherent simplicity, governed by very few constructs (knowledge, planning, performance measurement, and behavior), and simply explained as a function of the system's degrees of freedom and harmony between of constructs that govern the work environment within an organization.

V. Conclusion

This study was framed into the conceptualization phase of theory building to identify and to present propositions between constructs to explain the causalities that govern safety at work. By following a general method of theory building in applied sciences, and consistent with the principle of inherent simplicity from TOC, our findings indicate the existence of four constructs that govern safety at work: knowledge, planning, behavior, and performance measurement.

Moreover, each construct and its interconnections comprised a set of propositions expressed through a conceptual framework that explains the underlying issues in safety at work and put behavior as a key element. Furthermore, as a result of our analysis based on the stages in which every science has gone through (classification, correlation, and causal consistency), the phenomenon of safety at work was represented as a system in which the level of complexity depends on the interdependencies between constructs and harmony.

A major theoretical outcome from this research is a conceptualization narrative that defines the complexity of safety at work as a consequence of degrees of freedom (interdependencies between constructs) and harmony (absence of conflicts between constructs). We postulate that as much interdependent and harmonious is the system the less complex is safety at work. In that reasoning, both circumstances affect safety at work and determine whether safety at work is a complex or exceedingly simple matter. Although foster future research is highly encouraged to cover other phases of this theoretical model, this study presents generalizability regarding temporal and contextual factors discussed.

Finally, from the practitioner's perspective, our findings contribute to the improvement of safety practices at the organizational level by redefining their structures, connections and focusing on behavior-based safety under a broader perspective.

References

[1] Rae A, Provan D, Aboelssaad H, et al. A manifesto for Reality-based Safety Science. *Safety Science* 2020; 126: 104654.

[2] ILOSTAT. Statistics on safety and health at work, https://ilostat.ilo.org/topics/safety-and-health-at-work/ (2021, accessed 3 April 2021).

[3] Brocal F, González C, Sebastián MA, et al. Standardized risk assessment techniques: A review in the framework of occupational safety. In: van Gulijk C. Haugen S. BAVJEKT (ed) *Safety and Reliability - Safe Societies in a Changing World - Proceedings of the 28th International European Safety and Reliability Conference, ESREL 2018*. CRC Press/Balkema, pp. 2889–2896.

[4] ILO. International Labour Organization Web Page, https://www.ilo.org/global/topics/safety-and-health- at-work/lang--en/index.htm (2020, accessed 15 July 2020).

[5] Wang Y, Chen H, Liu B, et al. A systematic review on the research progress and evolving trends of occupational health and safety management: A bibliometric analysis of mapping knowledge domains. *Front Public Heal*; 8. Epub ahead of print 2020. DOI: 10.3389/fpubh.2020.00081.

[6] Heuvel S van den, Zwaan L van der, Dam L van, et al. *Estimating the costs of work-related accidents and ill-health: An analysis of European data sources - European Risk Observatory*. Luxembourg: European Agency for Safety and Health at Work, 2017. Epub ahead of print 2017. DOI: 10.2802/566789.

[7] Swanson RA, Chermack TJ. *Theory Building in Applied Disciplines*. San Francisco, CA, 2013. Epub ahead of print 2013. DOI: 10.1108/jchrm-06-2013-0023.

[8] Eden Y, Ronen B. *Approximately right not precisely wrong: Cost accounting pricing and decision making*. Great Barrington, MA: The North River Press, 2007.

[9] Whetten DA. What constitutes a Theoretical Development? *Acad Manag Rev* 1989; 14: 490–495.

[10] Goldratt EM. *What is the thing called Theory of Constraints and it should be implemented?* New York, NY, United States: The North River Press, 1990.

[11] Ikeziri LM, Souza FB de, Gupta MC, et al. Theory of constraints: review and bibliometric analysis. *Int J Prod Res* 2018; 57: 1–35.

[12] Goldratt EM. *The Choice*. Great Barrington, MA: The North River Press, 2008.

[13] Naor M, Bernardes ES, Coman A. Theory of constraints: Is it a theory and a good one? *Int J Prod Res* 2013; 51: 542–554.

[14] Lynham SA. General Method of Theory Building in Applied Disciplines. *Adv Dev Hum Resour* 2002; 4: 221–241.

[15] Simon HA. *Models of man*. Hoboken, NJ: Wiley, 1957.

[16] Zhang S, Zhang C. *Association Rule Mining - Models and Algorithms. Lecture Notes in Artificial Intelligence*. Berlin: Springer, https://www.springer.com/gp/book/9783540435334 (2002, accessed 11 October 2020).

[17] Isa N, Kamaruzzaman NA, Ramlan MA, et al. Market Basket Analysis of Customer Buying Patterns at Corm Café. *Int J Eng Technol* 2018; 7: 119–123.

[18] Kouzis-loukas M. *Analysing Customer Baskets*. Erasmus School of Economics, 2014.

[19] Gauss L, Lacerda DP, Cauchick Miguel PA. Module-based product family design: systematic literature review and meta-synthesis. *Journal of Intelligent Manufacturing*. Epub ahead of print 2020. DOI: 10.1007/s10845-020-01572-3.

[20] Alves FLD. *Data mining como suporte a tomada de decisão na priorização de estoques*. 2020.

[21] Tan PN, Steinbach M, Karpatne A, et al. *Introduction to Data Mining*. 2nd ed. New York: Pearson, https://www-users.cs.umn.edu/~kumar001/dmbook/index.php (2018).

[22] Hahsler M, Hornik K. New probabilistic interest measures for association rules. *Intell Data Anal* 2008; 11: 437–455.

[23] Cheng C-W, Lin C-C, Leu S-S. Use of association rules to explore cause-effect relationships in occupational accidents in the Taiwan construction industry. *Saf Sci* 2010; 48: 436–444.

[24] Mirabadi A, Sharifian S. Application of association rules in Iranian Railways (RAI) accident data analysis. *Saf Sci* 2010; 48: 1427–1435.

[25] Verma A, Khan SD, Maiti J, et al. Identifying patterns of safety related incidents in a steel plant using association rule mining of incident investigation reports. *Saf Sci* 2014; 70: 89–98.

[26] Ermel APC, Lacerda DP, Morandi MIWM, et al. Literature Reviews: Modern Methods for Investigating Scientific and Technological Knowledge. In: *Literature Reviews: Modern Methods for Investigating Scientific and Technological Knowledge.* Springer International Publishing, 2021. Epub ahead of print 2021. DOI: 10.1007/978-3-030-75722-9.

[27] Weick KE. What Theory is Not, Theorizing Is. *Adm Sci Q* 1995; 40: 385.

[28] Han S, Lee S, Peña-Mora F. Framework for a resilience system in safety management: A simulation and visualization approach. In: W. T (ed) *Proceedings of the International Conference on Computing in Civil and Building Engineering*. University of Illinois at Urbana-Champaign, United States: Nottingham, https://www.scopus.com/inward/record.uri?eid=2-s2.0-85069842960&partnerID=40&md5=f86ce5dd2d85bd49b1ceae1cef2ea53c (2010).

[29] Li H, Lu M, Hsu S-C, et al. Proactive behavior-based safety management for construction safety improvement. *Saf Sci* 2015; 75: 107–117.

[30] Porter LW, Bigley GA, Steers RM. *Motivation and Work Behavior*. 7th ed. Mc-Graw Hill/Irwin, 2002.

[31] Cohen BP. *Developing sociological knowledge: Theory and method*. 2nd ed. Chicago, IL: Nelson-Hall, 1989.

Appendix

A 1 – *Structure of the investigation report*

Category	Data field (required information)
Time-horizon (n=3)	Fiscal year Month Sequence
Location (n=5)	Business Unit Operation Unit Country Branch Geographic region
Individual (n=6)	Age Scholar level Technical background Job function Years of experience Years working for the company
Accident data (n=9)	Type of accident, e.g. Elevator. Equipment Lost days Level of severity Body’s part affected Nature of illness/injury Weekday Shift Location where the accident occurred
Process planning	Task condition, e.g. routine, non-routine

(n=7)	Job site (OTD status), e.g. on-time, delayed Worked hours in the circumstances of the event PPE: Was appropriate PPE being used? (Y/N) Tools: Were there appropriate tools available? (Y/N) JHA: Was it performed (Y/N) JHA: Was it performed according to the task? (Y/N)
Previous accidents/santions/audits (n=3)	Previous accident reported? (Y/N) Previous sanctions in the last 12 months? (Y/N) Audited in the last 12 months? (Y/N)
Training (n=3)	Hours of training(last 12 months) 10 rules training up to date? (Y/N) Has been trained for the task being performed (Y/N)
Behavior	Behavioral assessment in the last 12 months? (Y/N) Behavioral change observed recently? Psychological test performed during onboarding?
Violated rules	Technical rule violated?, e.g. PPE usage, fall protection etc Behavioral trap associated with the accidente?, e.g. Diminishing risks, lack of concentration etc.

A 2 – *Script R for association rules*

R Studio v. 4.0.5

```
# Require packages
if(!require(readxl)) install.packages("readxl")
if(!require(arules)) install.packages("arules")
if(!require(arulesViz)) install.packages("arulesViz")
if(!require(tidyr)) install.packages("tidyr")

# Load packages
library(readxl); library(arules), library(arulesViz), library(tidyr)

# Load dataset
data <- read_excel("Lost-time accidents Report.xlsx", sheet='DATA')
View(data)

# Adjust dataset
data_aj <- dados [, c(-2,-3,-4,-5,-6,-7,-8,-9)]
View(data_aj)

# Convert dataset into file .csv
write.csv(dados_aj,"AR.csv", quote=FALSE, row.names=FALSE)

# Convert dataset into transaction format
tr <- read.transactions('AR.csv', format = 'basket', sep=',')
tr
summary(tr)

# Create association rules
rules = apriori(tr, parameter=list(suppor = 0.5, conf = 0.8, minlen = 1, maxlen = 3))
```

```
rules
inspect(head(rules))

# Remove redundant rules
rules = rules[!is.redundant(rules)]
rules
inspect(rules)
result = inspect(rules)

# Print association rules
write.csv2(result, "Association rules.csv")
```