Applying Resilience Engineering to improve Safety Management in a Construction Site: Design and Validation of a Questionnaire

M. C. Pardo-Ferreira, J. C. Rubio-Romero, M. Martínez-Rojas

Abstract**—**Resilience Engineering is a new paradigm of safety management that proposes to change the way of managing the safety to focus on the things that go well instead of the things that go wrong. Many complex and high-risk sectors such as air traffic control, health care, nuclear power plants, railways or emergencies, have applied this new vision of safety and have obtained very positive results. In the construction sector, safety management continues to be a problem as indicated by the statistics of occupational injuries worldwide. Therefore, it is important to improve safety management in this sector. For this reason, it is proposed to apply Resilience Engineering to the construction sector. The Construction Phase Health and Safety Plan emerges as a key element for the planning of safety management. One of the key tools of Resilience Engineering is the Resilience Assessment Grid that allows measuring the four essential abilities (respond, monitor, learn and anticipate) for resilient performance. The purpose of this paper is to develop a questionnaire based on the Resilience Assessment Grid, specifically on the ability to learn, to assess whether a Construction Phase Health and Safety Plans helps companies in a construction site to implement this ability. The research process was divided into four stages: (i) initial design of a questionnaire, (ii) validation of the content of the questionnaire, (iii) redesign of the questionnaire and (iii) application of the Delphi method. The questionnaire obtained could be used as a tool to help construction companies to evolve from Safety-I to Safety-II. In this way, companies could begin to develop the ability to learn, which will serve as a basis for the development of the other abilities necessary for resilient performance. The following steps in this research are intended to develop other questions that allow evaluating the rest of abilities for resilient performance such as monitoring, learning and anticipating.

Keywords**—**Resilience engineering, construction sector, resilience assessment grid, construction phase health and safety plan.

I. INTRODUCTION

OVER time, systems and organizations have evolved and have increasingly become more complex, intractable and coupled. During all that time, different theories and models have emerged to support the management of safety in them. However, in the current scenario it is necessary to make a deep revision of the vision of the concept of safety in order to be able to continue advancing in its management and make it adapt accurately to the actual performance of the systems and organizations. Trying to apply theories or models that were conceived when the environment and the performance conditions of the systems and organizations were very different may not provide the best results. For this reason, this paper aims to introduce this new vision of safety from the framework of Resilience Engineering. For this, different innovative concepts such as Safety-I and Safety-II, Resilience Engineering and Resilience Assessment Grid are described. Based on these concepts, a new tool is proposed to support safety management in construction sites through the Construction Phase Health and Safety Plan.

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A. Safety-I and Safety-II

Traditionally, safety (Safety-I) is usually understood as the absence of accidents, incidents and failures, or, in other words, the absence of things that go wrong. Thus, when we approached safety and the problems related to it by understanding the things that go wrong, we look for its causes and establish the necessary mechanisms or measures so that these unwanted events or failures do not recur. In this way, a system is considered safer the smaller the number of adverse events that occurred. Therefore, safety is defined indirectly, that is, by adverse events that occur when there is no safety. One consequence of this is that safety management relies on measurements that refer to the absence of safety rather than to the presence of safety. Because the focus is on things that go wrong, there will be something to measure when safety is absent, but paradoxically nothing to measure when safety is present [1].

The concept of Safety-II proposes to change this traditional point of view and focus on what happens when safety is present, that is, when things are going well. Thus, a reactive approach to safety focused on accidents or failures (Safety-I) would be replaced by a proactive approach to safety focused on the daily or normal performance of the systems (Safety-II). Safety II is defined as a condition where the number of successful outcomes (meaning everyday work) is as high as possible [2]. This does not mean that Safety-II moves away from adverse outcomes, but that Safety-II is concerned with both adverse outcomes and successful outcomes. Since Safety-II establishes that there is no special mechanism for failures, both are the result of daily performance and variability that sometimes is not properly dampened and emerges as the failure. Efforts are aimed at understanding and strengthening daily performance since by ensuring that things go well, things that go wrong can be reduced. Thus, the evolution of the concept of safety involves not understanding safety as the freedom from unacceptable risks, to understanding safety as the ability to achieve success.

B. Resilience Engineering

At the beginning of the 21st century, Resilience Engineering (RE) was born. It is a new paradigm of safety management that focuses on how people can cope with complexity when they are under pressure to achieve success [3]. This new approach breaks with the traditional way of understanding safety (Safety-I) and redefines the concept of safety (Safety-II). The new paradigm of the RE emphasizes that when things go well in difficult circumstances, it is mainly due to the ability of workers to adapt, that is, their ability to recognize, absorb and adapt to changes and unforeseen events. In complex systems, people continually make adjustments on what has been devised, which allows them to achieve success, but even if only rarely, accidents emerge as a result of an incomplete analysis of current conditions [4]. Adjustments are a sine qua non condition, and procedures and instructions are incomplete due to complexity. Based on all this, the variability of the performance is revealed, not in the negative sense where the variability is seen as a deviation from some rule or standard, but in the positive sense where the variability represents the adjustments that are the basis for the safety and productivity. In this way, the variability of performance has to be managed, dampening it if it goes in the wrong direction and amplifying it if it goes in the right direction. For this, it is necessary first to recognize the variability of performance, second to monitor it and third to control it. Nevertheless, before it is necessary to understand how the system works, how it develops and changes its environment and how the functions can depend on and affect each other. This understanding can be developed by looking for patterns and relationships between events rather than causes of individual events, as was done up to now. Consequently, resilience is defined by Hollnagel [5] as “the intrinsic ability of a system to adjust its functioning prior to, during or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions”. In this definition, it must be taken into account that resilience is not a property of the systems but rather a characteristic of how the systems carry out their daily performance. It is not something that systems have but it is something that systems do [3].

C. Resilience Assessment Grid

Resilience Engineering establishes some essential requirements for the management process. These requirements are reflected in four abilities that organizations must manage properly if they want their performance to be resilient. According to Hollnagel [6], the essential abilities for resilience or potentials necessary for resilient performance are:

- *Respond: Knowing what to do*

Be able to respond to variability, disturbances and opportunities both daily and unforeseen, either adjusting the way things are done or activating prepared responses.

- *Monitor: Know what to look for*

Be able to monitor what is or could become a threat in the short term. This monitoring must encompass the system's own performance as well as changes in the environment.

- *Learn: Know what happened*

Be able to learn from experience, in particular to learn from the correct lessons of the right experience.

- *Anticipate: Knowing what to expect*

Be able to anticipate events, threats and opportunities in the future, such as possible interruptions, changing operating conditions, pressures and their consequences.

Resilience is a property of organization to adjust their functioning to performance conditions and the environment. Accordingly, the resilience of an organization cannot be measured. However, the ability of an organization to develop a resilient performance can be measured. Resilience Assessment Grid (RAG) is a set of questions to measure the potentials or abilities of an organization for resilient performance in order to manage them. Based on the information obtained through these questions, an organization will be able to know its weaknesses and what aspects it should improve to strengthen its abilities to have more resilience.

D. Construction Sector and Construction Phase Health and Safety Plan

Nowadays, Resilience Engineering is being applied through the RAG to different sectors of high-risk and complexity such as air traffic control, health care, nuclear power plants, railways or emergencies. In all these cases, the results have been very positive. For this reason, it could be interesting to apply this new vision of safety in other sectors such as construction. With this new approach, it is expected that better results can be achieved, since safety management continues to be a problem in the construction sector. In fact, the construction sector is one of the sectors with the highest number of accidents worldwide. According to the Occupational Safety and Health Administration in the United States,

> “nearly 6.5 million people work at approximately 252,000 construction sites across the nation on any given day. The fatal injury rate for the construction industry is higher than the national average in this category for all industries” [7].

In Europe, the situation is similar; more than one fifth of all fatal accidents at work in the EU-28 in 2015 took place within the construction sector [8]. In Spain, the sector of activity with the highest incidence rate in 2015 was the construction sector, above the national average in Spain [9]. Therefore, the importance of managing safety adequately in the construction sector is evident. Planning for safety before the start of the project execution phase is essential since it provides the necessary tools for safe performance during the execution. Construction Phase Health and Safety Plan arises like a key element since it is the fundamental element of planning which forms the basis for the management approach with risk assessment as its core theme [10]. This document should be focused on the key management and technical aspects of worker safety management. In addition, it should be taken into account that the lack of training or inadequate training of construction workers has been considered as one of the causes behind the sector's accident rates [11]. Hence, safety management in construction sites has to include the management of learning and training. In relation to this, [12] points out that different training was needed in the construction sector. Thus, the present paper has a dual purpose. On the one hand, the paper aims to develop a questionnaire which is intended to guide construction companies to take the first steps to evolve from Safety-I to Safety-II by developing the ability to learn as a basis for the development of the rest of the abilities necessary to have a resilient performance. On the other hand, the paper is intended to improve the usefulness of the Construction Phase Health and Safety Plan to turn it into an element that really contributes to the improvement of safety in construction by promoting learning.

In summary, the objective of this paper is to design and validate a questionnaire to assess the extent to which the Construction Phase Health and Safety Plan contributes to the ability to learn in a construction site.

II. Methodology

The present study has been developed in Spain during 2018. The research process was divided into four stages, as shown in Fig. 1:

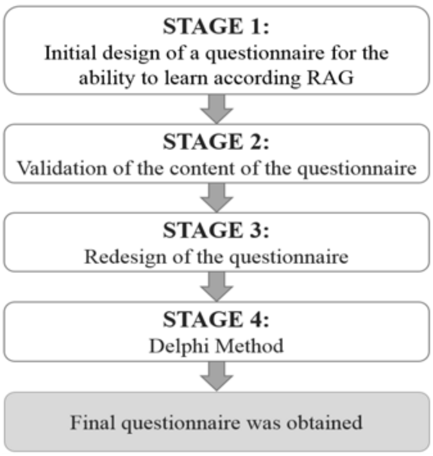

Fig. 1 Stages of the research process

Initially, the examples of detailed issues related to the ability to learn proposed by Hollnagel [6] were used as main source of information in order to design the items that would be included in the questionnaire. In addition, another set of questions designed according to the RAG for other organizations such as the Canadian City Emergency Department [13], the French National Railways [14], the Swedish Civil Aviation Administration [15], and the Australian Radiation Protection and Nuclear Safety [16], were used in the design process. The questionnaire was revised on three successive occasions by four experts specialized in the areas of occupational health and safety and construction and Resilience Engineering.

Secondly, the expert judgment technique was used to test the content validity through individual aggregate method. Corral [17] recommends that the group of experts be between three and five and be an odd number. In our case, three experts were selected in the areas of occupational health and safety and construction, and who were familiar with the principles and objectives of Resilience Engineering. These experts were different from those who participated in the initial design process. All of them had obtained a doctorate in engineering or architecture, had more than 10 years of experience in the construction sector and had knowledge in Resilience Engineering. The experts had to evaluate different aspects of each item questionnaire such as coherence, relevance and clarity [18]. For this purpose, they used 4-point Likert scales ranging as follows: 1. Does not meet the criteria; 2. Low level; 3. Moderate level; 4. High level. In addition, they evaluated the sufficiency of all the items together; that is, if the items that had been included in the questionnaire are sufficient to adequately measure the ability to learn necessary for resilient performance in a construction site. To do this, the same Likert scale from 1 to 4 was also used.

In order to ensure that the evaluations were carried out properly, some information was provided to the experts. In this way, a document summarizing the main key concepts of Resilience Engineering, Safety-I and Safety-II, as well as the RAG was provided. A form was also provided to collect the responses of the experts. The objective of the questionnaire, its dimensions and some brief instructions on how to fill it out were included in the first part of the form. According to Escobar-Pérez and Cuervo-Martínez [18], a description of the meaning of each value of the Likert scale of each aspect, that is, *coherence*, *relevance*, *clarity* and *sufficiency*, was also provided. Table I includes an example of the clarifications included in case of *coherence*:

TABLE I
Description of the Scale Used to Evaluate the Coherence of Each Questionnaire Item

COHERENCE: The item has a logical relationship with the dimension or indicator that it is measuring	
Values	Description
1. Does not meet the criteria	The item has no logical relation to the dimension
2. Low level	The item has a tangential relationship with the dimension
3. Moderate level	The item has a moderate relationship with the dimension it is measuring
4. High level	The item is completely related to the dimension it is measuring

Thirdly, the questionnaire items were analyzed based on the evaluations of the experts. All the items that obtained a score of 2 or 1 in any of the aspects analyzed were revised to be modified or eliminated.

Finally, the Delphi method was applied. According to [19], this method is “a systematic and interactive research technique for obtaining the judgment of a panel of independent experts on a specific topic". Thus, 17 experts were chosen for the study, all with university qualifications, experience in the construction sector and knowledge of the concept and principles of RE. The process consisted of asking the panel of experts to determine the importance of the items developed to be included in the questionnaire via the application of the Delphi method. For this, the experts used a 5-point Likert scale from unimportant (1) to very important (5). This method is based on the completion of multiple rounds. In the three successive rounds that were needed to obtain a consensus, the experts were given statistical details of the previous round, their individual assessment, the median and the absolute deviation. There was also a section that had to be completed explaining their reasons if their new response diverged substantially from that of the group. The process ends when the consensus is reached. According to Hallowel and Gambatese [19], the experts' consensus was considered to have been achieved when the absolute deviation was ≤0.5 on a 1-5 scale. If once reached the consensus, an item was considered as unimportant (1) or of little importance (2) would be removed from the questionnaire.

III. Results

In this section, the main results obtained in each of the stages described in the methodology are presented. During the design process developed in stage 1, the four experts who participated carried out three successive revisions of the 15 items initially proposed. These items were modified, eliminated or grouped during the review process based on the opinions of the experts. Consequently, a questionnaire with 10 items was obtained.

TABLE II
EVALUATION OF THE 3 EXPERTS OF THE QUESTIONNAIRE ITEMS BY INDIVIDUAL AGGREGATES METHOD

	Aspects evaluated by the experts											
	Expert 1				Expert 2				Expert 3			
Items	CO	R	CL	S	CO	R	CL	S	CO	R	CL	S
01	4	4	4	4	4	3	4	4	3	4	4	4
02	3	3	4		4	4	4		4	3	4	
03	4	4	3		4	4	4		4	3	4	
04	3	**2**	4		4	4	4		3	4	4	
05	4	4	4		4	4	4		3	4	4	
06	3	3	4		4	4	4		4	3	4	
07	4	4	4		3	4	4		4	3	4	
08	4	4	4		4	4	4		4	3	4	
09	4	4	4		4	4	4		3	4	4	
10	4	4	4		4	4	4		3	4	4	

CO=Coherence; R=Relevance; CL= Clarity; S=Sufficiency.

In the second stage, three experts evaluated the items by the method of individual aggregates. Table II shows the results of the evaluations of the questionnaire. The fourth item appears shaded in gray because it obtained a score of 2 in the aspect of relevance by expert 1; that is, this expert considered that the item had some relevance, but another item could be including what it measures. In the field of observations the expert added an explanation about his evaluation. In this sense, the expert indicated that perhaps this item may fit more with the ability to monitor.

In the third stage, we proceeded to redesign or eliminate those items with a score of 2 or 1. No item was eliminated. Nevertheless, the fourth item was modified to improve its meaning and its relation with the ability to learn. Initially, the item is redacted by the following statement:

The Construction Phase Health and Safety Plan establishes criteria to control that the time from reporting an incident (unexpected or unpredictable events) until a response is generated is acceptable.

After the redesign the following statement was included in the item:

The Construction Phase Health and Safety Plan establishes criteria to control that the time from reporting an incident (unexpected or unpredictable events) until such information is analyzed and learned from it is acceptable.

In the fourth stage, 17 experts supported the application of the Delphi method. As indicated in the methodology section, three rounds were necessary to reach the consensus of the experts on the importance of the items to be included in the questionnaire. No item scored 2 or less. Consequently, none of the questionnaire items was eliminated. Table III shows the statistical details of the three rounds for the questionnaire items for the ability to learn. For most of the items, the consensus among the experts was reached in the second round. Only one item needed a third round.

TABLE III
EVALUATION OF THE 17 EXPERTS OF THE QUESTIONNAIRE ITEMS BY DELPHI METHOD

	FIRST ROUND		SECOND ROUND		THIRD ROUND	
Items	Median	AD	Median	AD	Median	AD
01	5	0.71	5	0.47	-	-
02	4	0.76	4	0.29	-	-
03	4	0.53	4	0.53	4	0.29
04	4	0.65	4	0.41	-	-
05	4	0.65	4	0.24	-	-
06	4	0.47	-	-	-	-
07	4	0.82	4	0.24	-	-
08	4	0.71	4	0.35	-	-
09	4	0.53	4	0.29	-	-
10	4	0.47	-	-	-	-

AD=Absolute Deviation

Finally, the research process shown in this paper allowed the design and validation of a questionnaire with 10 items that would serve as a support to facilitate that the ability to learn for a resilient performance be properly developed during the execution of the tasks in a construction site. Table IV presents the final statements of each of the items.

Some clarifications must be taken into account to apply the questionnaire properly. On the one hand, this questionnaire should be considered as a diagnostic tool. Therefore, once it has been applied, it can be known which are the weaknesses and specific issues should be improved to increase the ability to learn from the companies involved in a construction site. Measures and priority action lines focus on learning can be established according to the results of the questionnaire. On the other hand, this questionnaire measures the ability to learn in a specific moment. Since this ability is something that the organization does during its daily performance. For that reason, it is necessary to periodically use this questionnaire in a construction site. In this way, it will be possible to know how this capacity evolves and if the applied measures are being effective.

TABLE IV
ITEMS OF THE FINAL QUESTIONNAIRE INCLUDED IN THE ABILITY TO LEARN

No. Item	Statement
L01	The Construction Phase Health and Safety Plan clearly establishes what type of incidents (unexpected or unpredictable events or events) should be reported.
L02	The Construction Phase Health and Safety Plan defines criteria to ensure that information on incidents (events or unexpected or unforeseeable events) is adequately investigated.
L03	The Construction Phase Health and Safety Plan establishes protocols focused on the reporting of incidents (events or unexpected or unpredictable events) to all organizations involved in the construction site.
L04	The Construction Phase Health and Safety Plan defines criteria to control that the time from reporting an incident (unexpected or unpredictable events) until such information is analyzed and learned from it is acceptable.
L05	The Construction Phase Health and Safety Plan establishes sufficient resources so that reports about these incidents (unexpected or unpredictable events or events) can be written.
L06	The Construction Phase Health and Safety Plan defines mechanisms to motivate employees to report incidents (unexpected or unpredictable events or events).
L07	The Construction Phase Health and Safety Plan defines mechanisms to learn about things that are going well, as well as those that go wrong.
L08	The Construction Phase Health and Safety Plan plans periodic meetings in which all the agents involved in the construction site analyze not only the things that have gone wrong, but also those that have gone well.
L09	The Construction Phase Health and Safety Plan establishes a formal procedure for the collection, classification and analysis of all the information and data received (reports, indicators ...).
L10	The Construction Phase Health and Safety Plan establishes a formal procedure to learn from this information (development of new procedures, training, redesign, reorganization ...).

IV. CONCLUSION

It has been more than 14 years since Resilience Engineering was born. In this time it has been developed and has been progressively penetrating in the scientific and business scope. Although there is still a long way to go to be widely recognized, the organizations that have begun to apply it recognize its value and importance. Therefore, it is essential that Resilience Engineering continues spread to favor the progress and improvement of safety management in complex organizations and systems. However, in the case of the construction sector, the experts who have participated in this study have highlighted the difficulty involved in the change from Safety-I to Safety-II, since it is necessary to change the mentality to approach safety management from a new perspective. Therefore, learning seems to be the best way to renew traditional ideas about safety management and focus on this new paradigm. But this change requires an adaptation process that must be supported by tools that help organizations know where to direct their efforts. The questionnaire presented in this paper aims to facilitate this task to the construction companies from the planning. This paper is part of a larger project. To continue with research in this area, the development of other questions focused on the other abilities for resilient performance appears as the next step in the research.

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REFERENCES

[1] E. Hollnagel, "Is safety a subject for science?" *Safety Science*, 67, pp. 547–588, Aug. 2014.
[2] E. Hollnagel. "Is justice really important for safety?" *Hindsight,* 18, pp.10-13. Dec. 2014.
[3] E. Hollnagel, D. D. Woods and N. Leveson Resilience engineering: Concepts and precepts. Ashgate Publishing, Ltd.; 2007.
[4] A. Rankin. “Making Sense of Adaptations: Resilience in High-Risk Work”. Diss. Linköping University Electronic Press, Jan. 2017.
[5] E. Hollnagel, “Prologue: the scope of resilience engineering”. “Resilience engineering in practice: A guidebook”. Ashgate Publishing, Ltd.; Nov. 2013.
[6] E. Hollnagel, “Safety-II in practice: developing the resilience potentials” Routledge, 2017.
[7] OSHA, “Worker Safety Series - Construction | Occupational Safety and Health Administration” (online) Available at: https://www.osha.gov/Publications/OSHA3252/3252.html (Accessed 10 Jul. 2018).
[8] EUROSTAT, “Accidents at work statistics - Statistics Explained” (online) Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Accidents_at_work_statistics (Accessed 10 Jul. 2018).
[9] Instituto Nacional de Seguridad e Higiene en el Trabajo, “Informe anual de accidentes de trabajo en España 2015”. Madrid. NIPO (en línea): 272-15-081-4. 2016.
[10] A. Griffith, and T. Howarth, “Construction health and safety management” Routledge, Sep. 2014.
[11] M. Gervais, “Good management practice as a means of preventing back disorders in the construction sector” Safety science, 41(1), pp. 77-88, Feb. 2003.
[12] M. A. Camino Lopez, D. O. Ritzel, I. Fontaneda and O. J. González Alcantara, "Construction industry accidents in Spain." *Journal of safety research* 39, no.5, pp. 497-507, Jan. 2008.
[13] G. Hunte and J. Marsen, “Engineering resilience in an urban emergency department, Part 2”. Fifth Resilient Health Care Meeting, Aug. 2016.
[14] E. Rigaud, C. Neveu, S. Duvenci-Langa, M. N. Obrist and S. Rigaud, "Proposition of an organisational resilience assessment framework dedicated to railway traffic management." In N. Dasdashi et al. (Eds.), Rail Human Factors: Supporting reliability, safety and cost reduction. pp. 727-732. Taylor and Francis. 2013
[15] D. Ljungberg, and V. Lundh. "Resilience Engineering within ATM-Development, adaption, and application of the Resilience Analysis Grid (RAG)" (LiU-ITN-TEK-G--013/080--SE), 2013.
[16] Australian Radiation Protection Nuclear Safety Agency (ARPANSA). “Regulatory Guide. Holistic Safety - Sample Questions” (REG-COM-SUP-240V v1.1), 2017.
[17] J. Y. Corral. “Validez y confiabilidad de los instrumentos de investigación para la recolección de datos”, *Revista Ciencias de la Educación*, Vol. 19, no.33 pp. 228-247. 2009.
[18] J. Escobar-Pérez, A. Cuervo-Martínez, “Validez de contenido y juicio de expertos: una aproximación a su utilización”, *Avances en medición.* 6(1), pp. 27-36, Apr. 2008.
[19] M. R. Hallowell, and J. A. Gambatese, "Qualitative research:

Application of the Delphi method to CEM research", *Journal of construction engineering and management* 136 (1), pp. 99-107, 2009.