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Composite leading indicator to assess the resilience engineering in occupational health & safety in municipal solid waste management companies

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ABSTRACT

Resilience Engineering is a paradigm that attempts to focus on learning from what works well rather than from failures. There have been few studies focusing on the quantitative evaluation of Resilience Engineering and none have been conducted for the Municipal Solid Waste sector. Composite indicators are a useful analytical tool for making decisions involving complex, multi-dimensional social phenomena, and we have used this approach to design a model to assess the level of implementation of Resilience Engineering in Municipal Solid Waste companies. Designed as a Composite Leading Indicator, based on the model created by Wreathall and Shirali et al., its weighting was defined by 22 Spanish and Italian Delphi experts. The results show a high level of consensus. With regard to the principle Top Management Commitment, a high value was assigned to raising awareness over the need to halt production when there is a safety risk. In connection with Culture of Learning, the experts emphasised the importance of establishing mechanisms to clearly define the person responsible for safety in each of the activities carried out in the company. In the area of Flexibility, they agreed on the importance of convincing workers that if they encounter a problem, the criterion to follow is to sacrifice production rather than safety to maintain the system.

1. Introduction

The increasing complexity of social and technical systems has aroused great interest in the concept of resilience in connection with occupational health and safety. Resilience does not focus on detecting errors but rather on learning from normal, successful operation, and improving performance by increasing variability. In essence, it tries to help people to cope with complexity when under pressure so as to achieve success, facilitating variability rather than constraining it. Although resilience is a relatively new concept, Resilience Engineering (henceforth RE) has been mostly studied in the context of high-risk complex systems, such as in the aviation, process and petro-chemical industries, and the nuclear power industry (Hollnagel et al., 2007), but its concepts also tend to be beneficial for other industries that have not been studied. Municipal Solid Waste (henceforth MSW) is an important sector all over the world. Although, in comparison with other industrial sectors its accident levels are not especially high, it is defined as a medium-risk sector due to the severity of some accidents (Junta de Andalucía, 2011).

In this context there are only a few methods which specifically focus on how to measure RE. It is important to note that, according to Resilicence Engineering, the safety is not a system property but it is something that a system or organization does. Therefore, the resilience itself can not be measured, only the potential for resilience can be measured (Hollnagel et al., 2007). From now on, when reference is made to measuring RE, we refer to measuring the potentials for resilicence. Even so, and there is a clear gap in assessing resilience using quantitative methods (Shirali et al., 2013). Assessment methods include Composite Indicators, which are analytical measurement tools that help in decision making via the simple evaluation of complex, multi-dimensional social phenomena, including RE. From another point of view, among the different types of indicator Leading Indicators are ways of measuring based on the measures taken to prevent accidents/incidents/dangerous events and not based on accidents/failures that have already occurred, as in the case of Lagging Indicators (Hinze et al., 2013). Leading Indicators, by their very nature, are closer to the key

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features of RE.

This study aims to develop a method for quantitative evaluation of Composite Leading Indicator for RE in the MSW sector. To do this we have based our approach on the RE principles defined by Wreathall (2006) and the 61 management measures in the questionnaire designed by Shirali et al. (2013). These have been examined and weighted by a panel of experts from Spain and Italy so that a Composite Leading Indicator could be defined which would allow the level of RE implementation to be assessed and quantified, thus facilitating decisions to improve RE. This study is part of a larger project promoted by the European Union and focus on health and safety management based on RE in MSW companies in different European Countries (Asses-Re-Tool).

1.1. Resilience engineering

RE in occupational health and safety first appeared in 2006 following the publication of the work edited by Hollnagel, Woods and Levenson (2007). Some writers have dealt with RE in specific sectors, such as Saurin and others who focused on building (Saurin et al., 2008, Costella et al., 2009, Saurin and Júnior, 2011).

Erik Hollnagel, David Woods and others based their work on Cognitive Systems Engineering (henceforth CSE). CSE, as a forerunner of RE, instead of seeing the man-machine interface as a system of mechanical principles, treats it as an adaptive system whose functions use knowledge of itself and the environment, and which adapts by planning and modifying actions. The principles of CSE also basically focus on helping people to cope successfully with complexity when under pressure. These principles have been set out in different forms. Saurin's study of the design of indicators for the application of CSE in the building sector points to 3 fundamental principles Saurin et al. (2008).

(1) *Flexibility or greater flexibility.* Only essential features should be specified and limits should be set which are tolerant of errors.
(2) *Learning.* More should be learnt from normal functioning than from errors. Monitoring procedures is as important as the procedures themselves.
(3) *Raising awareness.* Workers need to be aware of the status of safety barriers, and their limits.

This list of CSE principles was extended for RE by some authors, such as Wreathall (2006). Subsequently Grecco et al. (2012) developed these 6 principles into 43 purely qualitative measures, as Leading Indicators. Shirali et al. (2013) extended these individual measures to 61 and developed a model for assessment based on Principal Component Analysis.

The 6 principles, according to Shirali et al. (2013), had the following objectives:

(1) *Top-level commitment.* This section endeavours to manifest how much top management devotes to resilience engineering and safety.
(2) *Just culture or equity.* The aim of this section was identification of the potential obstacles to achieving a *culture of justice*.
(3) *Culture of learning.* The objective of these actions is understanding how much the plant tries to learn from incidents, near misses and mishaps.
(4) *Awareness and opacity.* Awareness and lack of clarity are critical for assessment of sacrifice judgements and also anticipation of future changes in the environment because those may affect the system's ability to function.
(5) *Preparedness.* The aim of this section was to understand that the plant can restructure itself in response to changes or pressures, and also that its work system design is tolerant of human error, and that the employees are able to make critical decisions on their own without having to wait for their boss.
(6) *Flexibility.* This section considered how much the plant actively anticipates problems and prepares for them.

The concept of RE is by no means easy to define. It has evolved progressively and we could say that there are now 4 types of RE, as suggested by Woods (2015):

(1) *Resilience as rebound:* This refers to the system's ability to recover and function normally again, return to equilibrium and the situation existing before the irregularity occurred, dealing with it and going back to the initial status. This ability depends a great deal on the structures developed before chaos comes, with a view to coping satisfactorily with surprises. In this case we refer to our response to surprises, disruption not envisaged in normal operation which the system is able to handle. Surprises pose a challenge and this will stimulate a process of learning and review.
(2) *Resilience as robustness:* This refers to the system's ability to absorb disruption and many people confuse robustness with resilience. Logically an increase in robustness increases the system's ability to absorb disruption. However, robust control only works in cases where disruption is well modelled. If the disruption is greater than what the system is designed to withstand, it is not overcome and the system will collapse.
(3) *Resilience as the opposite of brittleness*: Or how to extend the system's ability to cope with surprises. Systems in changing environments with finite resources are always striving to accommodate to challenges. If they are not able to continue making efforts to overcome their limitations the system is more brittle than robust. An obvious difficulty is that the limitations are usually uncertain. “Graceful extensibility”, as Woods terms it, is based on the dynamism needed to deal with a cascade of disruptions.
(4) *Resilience as sustained ability to adapt:* This refers to the system's ability to manage adaptability on a sustained basis, not merely the ability to adapt. For example, some systems are able to adapt to certain changes but when new types of change occur they collapse.

Le Coze for his part, says that the main ideas in RE can be synthesised as follows (2013):

(1) Understanding variability is more useful than studying errors.
(2) Studying normal performance is more relevant than studying incidents or accidents.
(3) Monitoring and contextual models are better than normative models.
(4) The engineering requirement and the risk assessment background.

The central idea of RE could thus be synthesised as the need to learn from normal functioning, facilitate variability, design limits that are tolerant to tangible and visible errors, and constantly monitor performance proactively with a view to detecting disruption sufficiently in advance. All these ideas would seem to point to the need for appropriate indicators to be designed. Fundamentally these indicators would tell us if the system's performance is exceeding the limits to which it is tolerant, allowing us to know what variability is normal, enabling us to monitor performance and make the necessary adjustments for it to function successfully without errors, and helping us to detect small signs, disruptions or indications that something may go wrong.

1.2. Leading Indicators

The indicators used in health and safety have been based traditionally on the numbers of accidents recorded, things that have already happened, events in the past. These indicators are currently referred to as “Lagging Indicators” (Toellner, 2001, Manuele, 2009). Generally speaking it is difficult for them to predict future events. Being based on past performance, they can rarely give us sufficient information to avoid future accidents (Grabowski et al., 2007, Mengolini and Debarberis, 2008). However, Leading Indicators, which refer to measures taken to prevent accidents and not to accidents and failures which