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

Juan Carlos Rubio-Romero[a,*], María del Carmen Pardo-Ferreira[a], Jose De la Varga-Salto[b], Fuensanta Galindo-Reyes[b]

[a] *School of Industrial Engineering, Universidad de Málaga, C/Dr. Ortiz Ramos, s/n, 29071 Málaga, Spain*
[b] *Universidad de Málaga, C/Dr. Ortiz Ramos, s/n, 29071 Málaga, Spain*

A R T I C L E I N F O

Keywords:
Resilience engineering
Municipal solid waste
Risk prevention
Indicators
Delphi
Composite leading
Health and safety
Occupational

A B S T R A C T

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 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

Table 1
Characteristics of Leading and Lagging Indicators (Hinze et al., 2013).

Leading Indicators	Lagging Indicators
Upstream	Downstream
Predictive	Historical
Heading	Trailing
Positive	Negative

have already occurred, can be used much more effectively as predictors. According to Grabowski Leading Indicators can be defined as conditions, events or measures which precede an accident or safety incident and have a predictive value. The characteristics of both approaches are summarised in Table 1 (Hinze et al., 2013).

Lagging Indicators are indicators which do not give information about why performance is below expected levels, while Leading Indicators are fundamentally geared to monitoring processes and allow one to take measures when there is some sign of failure, making these indicators more suitable in the RE context.

Leading Indicators can be classified as passive and active. Passive indicators, although they can be predictive to some extent on the macro level, are less effective than active indicators in the short term. Hinze et al. (2013) gives us the following examples for Leading Indicators in building: the number or percentage of supervisory staff and managers with certified safety qualifications, the number or percentage of contractors selected according to prior safety requirements, the requirement for each subcontractor to submit a site plan before being contracted, etc. Although these indicators are a clear sign of a good beginning, they give little short-term information for day-to-day activity and for quickly improving accident prevention. They can be used as predictors in medium- or long-term management and allow one to make improvements on that time scale.

Active Leading Indicators focus on helping with changes in the short term. The examples given by Hinze et al. (2013) are: the percentage of jobsite supervisors who have attended safety meetings in the workplace, the percentage of faults detected in safety inspections, percentage of negative test results in random drug tests, number of close calls, aggressive promotion of safety in the workplace by contractors, etc. As can be seen there are both quantitative and qualitative indicators.

RE indicators have been analysed by various authors. Øien et al. (2011a) and Øien et al. (2011b), designed a method for developing resilience based on early warning indicators. The studies by Herrera and Tinmannsvik (2006) and Herrera and Hovden (2008), both in the field of aviation, discuss how RE fosters the design of innovative safety indicators. From the analysis carried out it seems clear that, because of their proactive focus, leading indicators reflect the principles of RE better than lagging indicators, notwithstanding the value of the latter for RE in certain cases (2012), although the contingencies of their implementation must be analysed beforehand. These indicators, like RE, suffer from the disadvantage that they are not those normally required by legislation and logically require time and personnel and an effort to communicate and implement them, according to Hinze.

1.3. Composite indicators

Composite indicators are defined by the OECD as a mathematical combination (or aggregation) of the indicators that represent the different components of the concept one is trying to evaluate, based on an existing system, allowing it to be evaluated in multiple dimensions. Composite indicators are analytical measurement tools for making decisions and carrying out simple evaluations of complex, multi-dimensional social phenomena. They are not an end in themselves but a tool that facilitates decision making and are justified by their ability to facilitate the interpretation of information by users (Nardo et al., 2005).

RE is a complex, multi-dimensional concept and, like any management system, RE management calls for tools that help us to evaluate action that has been taken or is envisaged in the decision-making process. The search for indicators that are able to measure the overall degree of implementation of RE provides us with a multitude of different possible factors whose aggregation can be quite heterogeneous. Composite indicators are thus a valid alternative for measuring or quantifying the implementation of RE in a company (Nardo et al., 2005, Domínguez Serrano et al., 2011).

1.4. Methods for assessing RE

There are only a few methods that specifically focus on how to measure RE, or rather the potentials for resilience, and there is a clear gap when it comes to assessing resilience using quantitative methods, with further research being necessary (Shirali et al., 2013). This is considered a priority area for RE research (Righi et al., 2015). Grecco et al. (2012) published a qualitative model for Leading Indicators in RE. Shirali et al. (2013) extended it and gave it a quantitative dimension based on a questionnaire with 61 items classified under the 6 RE principles already referred to, using the Principal Component Analysis method for a processing factory. Rubio-Romero et al. (2018) and Achard et al. (2016) applied this method proposed by Shirali et al. (2013) and evaluated different jobs of MSW companies in Spain and Italy, as an initial part of the project presented in this paper. Costella et al. (2009) and Saurin and Júnior (2011) published other methods using the MAHS approach, based on OHSAS 18001 and ILO-OSH 2001, applied to the power distribution industry. Saurin et al. (2014) proposed six criteria for the retrospective evaluation of health and safety management systems based on RE and Woods et al. (2013) devised a method for selecting indicators to support the identification of problems of overlapping indicators. Huber et al. (2009) discussed how one could learn from RE-aligned indicators, based on an audit of the health and safety management system in a chemical plant.

The definition of comprehensive indicators for the evaluation of the implementation of RE, allowing companies to measure performance, is explored in this study. In particular it has been developed for the MSW sector, based on the principles proposed in the model by Wreathall (2006) and the 61 measures corresponding to the 6 principles listed by Shirali et al. (2013). It has been designed as a weighted additive aggregation composite indicator, via the definition of qualitative weighting by a Delphi type panel of 22 Spanish and Italian experts in the MSW sector. In this way, they assigned the weights considering the organisational peculiarities of the MSW sector in the areas of manageability and coupling. For example, with regard to the principle of "preparation" so that the system is human-error tolerant and employees are able to make critical decisions on their own without having to wait for their boss, the weight assigned by the experts for the MSW industry is not the same as it would be for an organisation with greater levels of coupling and manageability, such as the nuclear industry, or other organisations with lower levels of these two factors, such as the Post Offices.

The advantages of this type of indicator are described by Nardo et al. (2005). They point out that using a panel of experts to define the indicators makes it highly likely that the results will be legitimate, as they are based on the opinions of people with a profound knowledge of the subject and the weighting system is free from technical manipulation. The disadvantages include a lower degree of reliability caused by the effect of local conditions, which may mean that the weighting assigned by the experts is not transferable from one place to another. Moreover, the weighting may not reflect the importance of each individual indicator but rather the urgency or need for something to be done, meaning that the indicator in question is overvalued. There are undoubtedly many indicators that require mentally grasping the problem as a whole before assigning weighting, and this difficulty can introduce inconsistencies (Nardo et al., 2005). To minimise the problems of a local focus, the experts in the MSW sector were drawn from two countries, Italy and Spain, and the homogeneity of their responses was analysed. The number of indicators is high because of the complexity of the problem.

2. Methodology and calculations

The objective of the study was to define the main Composite Leading Indicator for the overall evaluation of Resilience Engineering in the management of occupational health and safety in municipal solid waste.

The Composite Leading Indicator was designed based on 61 variables corresponding to the 61 items in the questionnaire designed by Shirali to evaluate RE (Shirali et al., 2013), questions which were, in turn, grouped according to the principles of Wreathall (2006) relating to RE. The indicator designed for this study is intended to provide a different evaluation of the weight of the contribution made by the 6 principles and 61 variables to Resilience Engineering. The indicator thus consists basically of the sum of these weights multiplied by the variables.

The process for designing the indicator, consisted basically of asking a panel of experts to weight the 61 variables and 6 principles in the questionnaire via the application of the Delphi method. The indicator would thus respond to the expression (1) shown below in Fig. 1, and the process of defining the indicator, which will be explained more fully in due course, can be summarized as shown in Fig. 2.

To explain it in more detail, the questions in the original Shirali questionnaire were reformulated, translated into Spanish and Italian and adapted to the MSW sector. The questionnaire was revised on 4 successive occasions by 4 experts in the areas of occupational health and safety and MSW, who were familiar with the principles and objectives of Resilience Engineering. During this process, if minor doubts arose regarding the exact meaning of the items, we contacted one of the authors, Shirali, to ensure that the sense of the questionnaire was not distorted. The questions were reformulated as management measures in the form of propositions or statements, although the questionnaire was essentially unchanged.

To define the Job Global Value (JGV) Composite Leading Indicator, which would make it possible to measure the degree to which RE was implemented for each job in a company, each of the 6 principles included in the JGV were defined in turn as a Composite Leading Indicator, as seen in Fig. 1.

The identification of the types of weighting and the variables in the model represented are explained below:

- The categories of weighting established via the Delphi analysis for each of the 61 measures within each of the 6 principles are referred to as w_{tmc_i}, w_{jc_i}, w_{cl_i}, w_{ao_i}, w_{f_i}, w_{p_i}, where the letters following the "w" are the lower case initials of the principle corresponding to the group.
- The 61 variables/measures for evaluating the implementation of the RE principles in the jobs of a company, are classified as: tmc_i, jc_i, cl_i, ao_i, f_i, p_i with values from 1 to 5, which will be obtained when the questionnaire is applied to a particular case. Once again the lower case initials of the principle for the group of measures are used.
- The weighting for the 6 principles in the Delphi study uses the following references: W_{TMC}, W_{JC}, W_{CL}, W_{AO}, W_F, W_P, where, once again, the letters following the "W" are the initials of the relevant principle but upper case this time.
- The 6 principles for evaluating the RE in a job are referred to as RE_{TMC},RE_{JC},RE_{CL},RE_{AO},RE_P,RE_F with values from 1 to 5, which will be obtained when the questionnaire is applied to a particular case. Once again the upper case initials of the principles are used in the subscript.

The panel of Delphi experts (Nardo et al., 2005, Domínguez Serrano et al., 2011, Ugwu et al., 2006) evaluated the 61 management measures or variables and assigned them a weighting, as they also did with each of the 6 principles, as explained before. In order to develop a Composite Indicator in line with the specific characteristics of the sector, 12 Italian and 10 Spanish experts were chosen for the study, all with university qualifications, experience in the MSW sector and knowledge of the concept and principles of RE. The number of experts was considered appropriate as the average error for a group falls exponentially to a sample size of approximately 17. Malla and Zabala (1978) thus place the ideal number of experts between 15 and 20, for León and Montero (2003) it is 10–30, and for Gordon (1994) it is 15–35.

The profiles of the experts in the Delphi group can be seen in Table 2.

The Delphi study ran from December 2014 to April 2015. The experts weighted each of the 61 statements regarding RE classified under the 6 principles mentioned above. Thus, weighting for each of the 61 RE measures was established, based on their priority within each principle, according to the median.

The 6 principles were also weighted, using a Likert scale from 1 to 5 (1: "very low"; 2: "low"; 3: "medium"; 4: "high"; 5: "very high"). Communication was by means of e-mail, thus ensuring the anonymity of the participants and preventing any expert from influencing the others. In the 3 successive rounds that were needed to obtain a consensus the experts were given statistical details of the previous round, their individual assessment, the interquartile range, and standard 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.

Two requirements had to be met before the opinions of the experts on each statement constituted a consensus. Firstly the relative interquartile range had to be ≤ 0.5, and secondly the percentage of responses in the interval median $\pm$ 1 had to be greater than 80% (Landeta, 2002).

When the consensus had been established, we checked to see whether there was coincidence within the group of experts from each country with regard to the priority they had assigned to the statements and principles regarding RE, in order to make sure that the results would be valid for both countries and that one group had not influenced

$$RE_{JC} = w_{jc_1} * jc_1 + \cdots + w_{jc_{11}} * jc_{11} \qquad RE_{AO} = w_{ao_1} * ao_1 + \cdots + w_{ao_{11}} * ao_{11} \qquad RE_F = w_{f_1} * f_1 + \cdots + w_{f_6} * f_6$$

$$JGV = W_{TMC} * RE_{TMC} + W_{JC} * RE_{JC} + W_{CL} * RE_{CL} + W_{AO} * RE_{AO} + W_P * RE_P + W_F * RE_F \qquad (1)$$

$$RE_{TMC} = w_{tmc_1} * tmc_1 + \cdots + w_{tmc_9} * tmc_9 \qquad RE_{CL} = w_{cl_1} * cl_1 + \cdots + w_{cl_{15}} * cl_{15} \qquad RE_P = w_{p_1} * p_1 + \cdots + w_{p_9} * p_9$$

Fig. 1. Expression of the proposed Composite Leading Indicator.

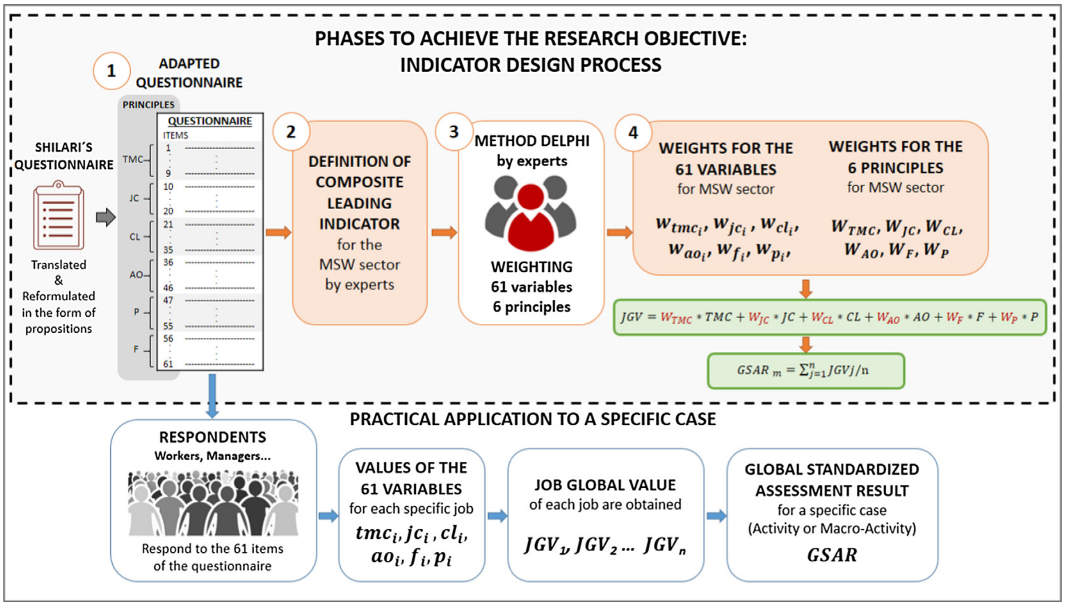

Fig. 2. Design process for the indicator and its application.

the other.

To determine this we first carried out an inferential statistical analysis preceded by a Levene test to verify the homogeneity of the variances in the two groups. The results of this first analysis provide information on whether equal variances should be taken or not (equal variances if $p \geq 0.05$) for the best results in the second analysis. The second analysis consisted of applying the Student's T test for equal means in order to verify that both groups coincided in their view of the priorities assigned to the statements and principles regarding RE. As in the previous test a significance level of $p < 0.05$ was established, which enabled us to verify our hypothesis with a 95% confidence level.

In the second round of the Delphi analysis consensus was obtained for most of the measures. The relative interquartile range was less than 0.5 for only one of them, while the T test failed for 9 of the statements. A third Delphi round was consequently held.

SPSS V.21 was used for the statistical analysis.

In this way, to apply the model we have defined in order to evaluate RE with the Composite Leading Indicator (Job Global Value-JGV), it would be sufficient to evaluate (from 1 to 5), the implementation of each of the 61 measures or variables as tmc_i, jc_i, cl_i, ao_i, f_i, p_i, for each job, and then add them up, also obtaining a value for each of the 6 principles, as shown in the following expressions ((2)-(7)), and for the Job Global Value for the job (8):

$$RE_{TMC} = \sum_{i=1}^{9} w_{tmc_i} * tmc_i(\%) \tag{2}$$

$$RE_{JC} = \sum_{i=1}^{11} w_{jc_i} * jc_i(\%) \tag{3}$$

$$RE_{CL} = \sum_{i=1}^{15} w_{cl_i} * cl_i(\%) \tag{4}$$

Table 2
Experience and training of the Delphi analysis experts.

Profession	Experience working in health and safety (years)	Experience with MSW (years)
Doctor of engineering	45	14
Doctor of engineering	25	33
Master's degree in engineering	12	12
Master's degree in engineering	23	23
Master's degree in engineering	20	22
Master's degree in engineering	3	3
Master's degree in engineering	2	4
Master's degree in engineering	5	5
Doctor of engineering	30	32
Doctor of engineering	25	20
Master's degree in engineering	1	/
Master's degree in engineering	1	4
Master's degree in engineering	2	13
Master's degree in engineering	1	6
Master's degree in geography	6	10
Master's degree in engineering	5	10
Master's degree in engineering	10	10
Master's degree in law	5	16
Master's degree in law	10	10
Master's degree in engineering	10	10
Master's degree in engineering	5	5
Master's degree in engineering	1	5

$$RE_{AO} = \sum_{i=1}^{11} w_{ao_i} * ao_i(\%) \tag{5}$$

$$RE_P = \sum_{i=1}^{9} w_{p_i} * p_i(\%) \tag{6}$$

$$RE_F = \sum_{i=1}^{6} w_{f_i} * f_i(\%) \tag{7}$$

$$JGV = W_{TMC} * RE_{TMC} + W_{JC} * RE_{JC} + W_{CL} * RE_{CL} + W_{AO} * RE_{AO} + W_P * RE_P + W_F * RE_F \tag{8}$$

To obtain an overall assessment for a series of jobs, for example in an activity or macro activity within an MSW company, or for the company as a whole, a *Global Standardized Assessment Result (GSAR)* can be defined. This is calculated by adding the results obtained for each of the *n* jobs in the activity or in the company and calculating the average. This will facilitate comparison with other companies with different numbers of employees or with the company itself at different times.

$$GSAR_m = \sum_{j=1}^{n} JGVj/n \tag{9}$$

The results for each principle, for JGV and for GSAR will be between 1 and 5.

3. Results

The results of the descriptive statistical study of the responses obtained in the Delphi analysis from the experts in both countries showed a common viewpoint from the start.

Analysis of the weight of the 9 RE management measures corresponding to the first principle of "Top Management Commitment" (see Appendix Table 7) showed that the experts assigned a very high priority to measure tmc_5 (Stop production when safety is at risk and make staff aware of this) and medium priority to measure tmc_2 (Measures to make recognition for work well done visible throughout the company). Low priority was assigned to tmc_4 (Production should not always be the top priority above everything else, but considered as important as safety by managers and supervisors), with the other measures related to this principle receiving high priority.

An analysis of the results for the weight of the RE measures related to the second principle, "Just Culture" (see Appendix Table 8) shows a tendency to assign medium scores. Of the eleven measures, four were given medium priority: jc_5 (Involving workers in general decision making by managers), jc_9 (Developing a clear perception of team spirit in the working environment), jc_{10} (Evaluating worker performance considering safety as well as other questions such as productivity) and jc_{11} (Reducing paperwork and bureaucracy so that they do not have a negative effect on job safety). Measure jc_8 (Organising meetings on safety issues at work, with employees in different departments, categories and levels) was given a priority score of 3.68 by both countries' experts for the values assigned to the Just Culture principle.

In their analysis experts assigned high priority to the 15 measures corresponding to the third principle, "Culture of Learning" (see Appendix Table 9), except cl_4 (Introducing mechanisms to debate and discuss risks in the workplace) and cl_7 (Taking the necessary steps to actively create a good Culture of Learning) which were given medium priority. Measure cl_{15} (Establishing mechanisms for the person responsible for safety in each of the activities taking place in the company to be clearly identified) was given a priority level of 4.5 (high-very high).

Similarly, in their analysis of the weight of the 11 measures corresponding to the fourth principle ("Awareness and Opacity") (see Appendix Table 10) it can be seen that the experts assigned a high priority to nearly all of them. Low priority was assigned to only two: ao_1 (Defining tasks that do not need to be carried out simultaneously) and ao_2 (Defining objectives that are not opposed).

In their analysis of the weight of the 9 measures corresponding to the fifth principle ("Preparedness") (see Appendix Table 11) it can be seen that the experts also assigned a high priority to them. However, measure p_3 (Motivating workers to talk to their peers and to managers about their concerns in connection with safety) was assigned a priority level of 3.5 and measure p_6 (Establishing measures to make staff aware that unexpected events or incidents related to safety often occur in the workplace) was assigned 3.32.

The experts assigned a higher priority to the 6 measures corresponding to the sixth principle ("Flexibility") (see Appendix Table 12). Very high priority was assigned to measures f_1 (Providing mechanisms for workers to have the best access to sources of help [prevention service, special installations, other company services, availability of time, etc.] to deal with unexpected safety incidents) and f_2 (Convincing workers that if they encounter a problem where they have to decide between sacrificing safety or production, the rule is to sacrifice production for the sake of safety, so that the system can be maintained). The other measures in this group were assigned high priority.

Thus, all 6 principles were analysed (see Appendix Tables 13) and all were assigned high priority, from 3.91 to 4.55. RE_{TMC} (Top Management Commitment) was assigned very high priority, 4.55.

As can be seen in Appendix (Tables 7–13) the T test for equal means verifies our initial hypothesis, confirming, with a confidence level of 95%, that the views of the experts from the two countries coincide in the values assigned to most of the management measures for RE, except measures ao_1 and ao_6 (Assuming that safety has a cost, not proposing cutbacks for this reason) under principle 4, Awareness and Opacity, and cl_4 under principle 3, Culture of Learning. As there are no great differences in the results of the T test (Diff. in means $< |1|$), it can be considered that the consensus of the group is confirmed. The same analysis applied to the principles (see Table 13) shows that the experts from both countries coincide in the values they assign to the RE principles overall, with the exception of RE_P, the Preparedness principle. Once again, there are no great differences in the results of the T test (Diff. in means $< |1|$), and we can consider that the consensus of the group is confirmed.

Finally, as a summary of our results, the "W" weighting for the 6 RE principles and the "w" weighting for the 61 measures are shown in Table 3. The weighting will be the same for any company in the MSW sector to be assessed.

The expression of the Composite Leading Indicator referred to as the specific JGV indicator for the evaluation of RE in a job in an MSW sector activity, consisting of 61 variables with their corresponding weighting, would thus be as shown in the following expression (10). The equation (10) does not show the 61 weights of the 61 corresponding variables in a single expression because of their extent. We only give the weight of the first variable and the last for each principle (see Fig. 3). For the weights w_{tmc_i}, w_{jc_i}, w_{cl_i}, w_{ao_i}, w_{f_i}, w_{p_i}, of the variables not included in the expression (10), see Table 3.

The Standardized Composite Indicator for the macro activity or business as a whole (GSAR) would thus be simply determined by a calculation using expression (9).

4. Application example

In this section an example of application is presented, following the procedure described in the last section, synthesised in Eq. (10).

The example chosen is a company responsible for the public collection and delivery of solid urban waste in the city of Málaga, Spain. The 61-item questionnaire was completed by workers from the jobs that participated in the Collection and Delivery Service according to Table 4. A total of 212 questionnaires were filled out, 205 of which were valid, distributed as shown by different jobs.

To apply the Composite Leading Indicator proposed, we gave each

Top Management Commitment		
Weight	Median	Weight Value
w_{tmc_1}	4.00	0.1143
w_{tmc_2}	3.00	0.8570
w_{tmc_3}	4.00	0.1143
w_{tmc_4}	3.00	0.8570
w_{tmc_5}	5.00	0.1429
w_{tmc_6}	4.00	0.1143
w_{tmc_7}	4.00	0.1143
w_{tmc_8}	4.00	0.1143
w_{tmc_9}	4.00	0.1143
Total		1

Just Culture		
Weight	Median	Weight Value
w_{jc_1}	4.00	0.1013
w_{jc_2}	4.00	0.1013
w_{jc_3}	4.00	0.1013
w_{jc_4}	4.00	0.1013
w_{jc_5}	3.00	0.7590
w_{jc_6}	4.00	0.1013
w_{jc_7}	4.00	0.1013
w_{jc_8}	3.50	0.8860
w_{jc_9}	3.00	0.7590
$w_{jc_{10}}$	3.00	0.759
$w_{jc_{11}}$	3.00	0.7590
Total		1

Culture of Learning		
Weight	Median	Weight Value
w_{cl_1}	4.00	0.6.840
w_{cl_2}	4.00	0.6840
w_{cl_3}	4.00	0.6840
w_{cl_4}	3.00	0.5130
w_{cl_5}	4.00	0.6840
w_{cl_6}	4.00	0.6840
w_{cl_7}	3.00	0.5130
w_{cl_8}	4.00	0.6840
w_{cl_9}	4.00	0.6840
$w_{cl_{10}}$	4.00	0.6840
$w_{cl_{11}}$	4.00	0.6840
$w_{cl_{12}}$	4.00	0.6840
$w_{cl_{13}}$	4.00	0.6840
$w_{cl_{14}}$	4.00	0.6840
$w_{cl_{15}}$	4.50	0.7690
Total		1

Awareness and Opacity		
Weight	Median	Weight Value
w_{ao_1}	3.00	0.7140
w_{ao_2}	3.00	0.7140
w_{ao_3}	4.00	0.9520
w_{ao_4}	4.00	0.9520
w_{ao_5}	4.00	0.9520
w_{ao_6}	4.00	0.9520
w_{ao_7}	4.00	0.9520
w_{ao_8}	4.00	0.9520
w_{ao_9}	4.00	0.9520
$w_{ao_{10}}$	4.00	0.9520
$w_{ao_{11}}$	4.00	0.9520
Total		1

Preparedness		
Weight	Median	Weight Value
w_{p_1}	4.00	0.1159
w_{p_2}	4.00	0.1159
w_{p_3}	3.50	0.1014
w_{p_4}	4.00	0.1159
w_{p_5}	4.00	0.1159
w_{p_6}	3.00	0.8700
w_{p_7}	4.00	0.1159
w_{p_8}	4.00	0.1159
w_{p_9}	4.00	0.1159
Total		1

Flexibility		
Weight	Median	Weight Value
w_{f_1}	5.00	0.1923
w_{f_2}	5.00	0.1923
w_{f_3}	4.00	0.1538
w_{f_4}	4.00	0.1538
w_{f_5}	4.00	0.1538
w_{f_6}	4.00	0.1538
Total		1

6 Principles			
Principle	Weight	Median	Weight Value
Top Management Commitment (RE_{TMC})	W_{TMC}	5.00	0.20
Just Culture (RE_{JC})	W_{JC}	4.00	0.16
Culture of Learning (RE_{CL})	W_{CL}	4.00	0.16
Awareness and Opacity (RE_{AO})	W_{AO}	4.00	0.16
Preparedness (RE_{P})	W_{P}	4.00	0.16
Flexibility (RE_{F})	W_{F}	4.00	0.16
Total			1

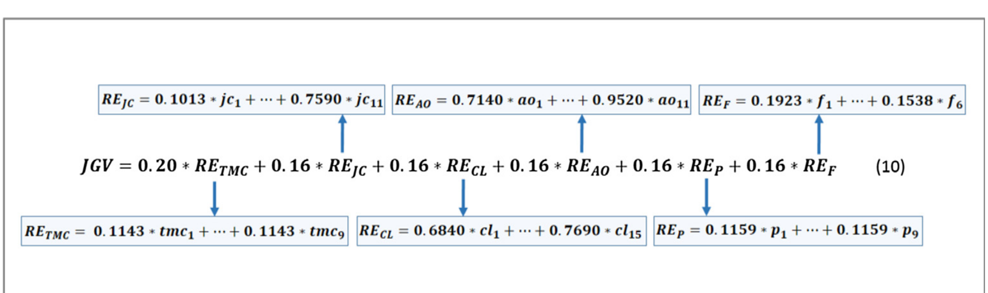

Fig. 3. Expression of the Composite Leading Indicator for the MSW sector.

Table 4
Number of questionnaires obtained for the jobs in the Collection and Delivery Service macro activity.

Jobs of macro activity of Collection and Delivery Service	Number of questionnaires
Cleaning Operator	95
Collection Operator	24
Driver	50
Machinist 2nd	10
Maintenance Operator	13
Management	19
Total	212
Valid questionnaires	205
Percentage of valid questionnaires	96.70%

of the 61 variables the value of the arithmetical average of the responses given by the employees who completed the questionnaire. These 61 average values, organized according to the 6 principles, for the position of Cleaning Operator, which we have used as an example, can be seen in Table 5. In the bottom row we can see the value assigned to each of the principles for the position of Cleaning Operator. The Global Value for the position of Cleaning Operator (JGV) would be 3.5, as can be seen in Table 6. In the same table we can also see the GSAR for Collection and Delivery as a whole, 3.42.

The GSAR value obtained could help us to design policies for improving RE in the company. For example, although this result is above the mid-point on the scale (2.5) there is scope for improving RE in this Collection and Delivery Service company up to the maximum of 5. Since, of the 6 principles, the greatest weight for the sector, 0.2, corresponds to Top Management Commitment, improvements affecting the 9 variables forming the RE_{TMC} principle would lead to a proportionally greater increase than those affecting principles that carry less weight. The measures that are valued for each of the 9 variables relating to the principle can be seen in Shirali et al. (2013). For example, variable number 5 in the first principle of RE_{TMC} carries the greatest specific weight within this principle and concerns evaluating management's willingness to encourage employees to stop work if they observe a safety hazard. Measures in this respect could thus make an effective contribution to improving RE in the company. If we consider the JGV values for each job, we see that the position of Driver is assigned the lowest, 3.18, suggesting that efforts to make improvements in this job should be a priority, followed by Machinist 2nd and Management, which also had low RE_{TMC} ratings.

The results in our example also show that the principles receiving the lowest scores were Culture of Learning, Just Culture and Flexibility, the latter being rated lowest in the different jobs overall. To improve

Table 6
Values of the job global value and global standardized assessment result for the collection and delivery service.

Jobs of collection and delivery service	RE_{TMC}	RE_{JC}	RE_{CL}	RE_{AO}	RE_{P}	RE_{F}	JGV	GSAR
Cleaning operator	3.82	3.32	3.37	3.52	3.66	3.24	3.50	3.42
Collection operator	3.82	3.32	3.37	3.52	3.66	3.24	3.50	
Driver	3.36	2.96	3.00	3.28	3.42	3.03	3.18	
Machinist 2nd	3.54	3.11	3.20	3.52	3.89	3.00	3.38	
Maintenance operator	4.02	3.63	3.46	3.54	3.58	3.22	3.59	
Management	3.53	3.37	3.32	3.43	3.56	3.09	3.39	

the company's capacity in this respect, 6 types of measure could be implemented corresponding to the 6 variables that affect this principle, the first two being those that have the greatest weight according to the indicator designed for the sector. For example, measures affecting the first variable, aimed at making resources available to help employees cope with unexpected events, contribute 19.23% to the principle, making management efforts in this area more effective than with other variables that carry less weight.

5. Discussion

In general terms, it can be seen that one of the greatest differences between the median values assigned by the experts from the two countries to the weighting of the measures regarding RE for MSW companies occurs with tmc_8 (Keeping management and superiors always alert for risks of all types - organisational, human and technological - that can threaten good functioning). The Spanish experts assigned it high priority while the Italian experts considered it to be a medium priority. In the case of jc_8 (Organising meetings about safety in the workplace, with workers in different categories or levels and different departments) the Spanish experts assigned it medium priority while the Italians assigned it high priority. Measure cl_{15} (Establishing mechanisms so that the person responsible for safety in each of the activities taking place in the company is clearly identified) was given a high priority level by the Spanish experts and a very high priority by the Italians.

The standard deviation for the evaluation of the measures and the RE principles by the experts from the two countries was somewhat smaller for the Spanish experts than the Italians. Even so, as has already been seen, the validity of the results is justified in both cases. It should be remembered that the participation of experts from two different countries minimises the danger of local effects.

We would also highlight the homogeneity of the evaluations of the 6 principles, and the fact that few indicators carry less weight than

Table 5
Values of the 61 measures/variables and the 6 RE principles obtained for the Cleaning Operator Job.

Variable	Variable Value	Variable	Variable Value	Variable	Variable Value	Variable	Variable Value	Variable	Variable Value	Variable	Variable Value
tmc_1	3.75	jc_1	4	cl_1	4	ao_1	3.25	p_1	3.5	f_1	3.25
tmc_2	3.75	jc_2	3.75	cl_2	3.75	ao_2	3	p_2	3.5	f_2	3
tmc_3	4	jc_3	3.5	cl_3	3.25	ao_3	3.25	p_3	4	f_3	3.75
tmc_4	3.5	jc_4	3	cl_4	3.75	ao_4	3.75	p_4	4	f_4	3
tmc_5	4	jc_5	2.75	cl_5	3	ao_5	3.75	p_5	4	f_5	3.25
tmc_6	3.25	jc_6	3.5	cl_6	2.75	ao_6	3.5	p_6	3.75	f_6	3.25
tmc_7	4	jc_7	3	cl_7	3.25	ao_7	3.5	p_7	3.5		
tmc_8	4	jc_8	3	cl_8	3	ao_8	3.5	p_8	3.25		
tmc_9	4	jc_9	3.75	cl_9	3.25	ao_9	3.75	p_9	3.5		
		jc_{10}	3	cl_{10}	3.5	ao_{10}	3.25				
		jc_{11}	3	cl_{11}	3.75	ao_{11}	4				
				cl_{12}	3						
				cl_{13}	3						
				cl_{14}	3.5						
				cl_{15}	3.75						
RE_{TMC}	3.82	RE_{JC}	3.32	RE_{CL}	3.37	RE_{AO}	3.52	RE_{P}	3.66	RE_{F}	3.24

others, which coincides with the results obtained in the study of evaluation by workers via a questionnaire carried out by Shirali et al. (2013) in the processing industry. Generally speaking all the principles are evaluated similarly, being assigned a high priority level, except the principle of Top Management Commitment, which was rated a very high priority. The importance given to Top Management Commitment reflects the importance given to research focusing on the management of health and safety from a more traditional position, as pointed out by Häkkinen some years ago (1995).

For the 61 measures evaluated, of note is the high rating assigned to raising awareness about the need to stop production when there are safety hazards. This was true in connection with top management commitment and also for successfully communicating the principle of flexibility to employees so that they will prioritise safety over production in the event of a conflict, reflecting one of the main concerns of RE, the trade-off between safety and productivity. This support for management as a priority objective was emphasised by Madni and Jackson (2009), among many others writing on RE who refer to the same need.

Another notable result is the need to establish the necessary mechanisms for the person responsible for safety in each of the company's activities to be clearly identified and to provide mechanisms for employees to have the best access to sources of help, so that they can deal with unexpected safety incidents, both of these being related to the Culture of Learning principle. In their study focusing on practitioner's experiences in the operationalization of Resilience Engineering, Lay et al. (2015) emphasised how important it is for those who have knowledge of safety to act as creators and facilitators, making it available to all, as well as using this knowledge themselves. This is not feasible in organisations above a certain size if they are not clearly identified, so that non-experts will recognise them and can ask for their help.

6. Conclusions

Although RE cannot be considered a new concept on the theoretical level, it is a new field when it comes to the quantitative evaluation of an organisation's RE potential. We have some qualitative tools and very few quantitative ones, none being based on composite indicators that allow for a comprehensive assessment that will facilitate measurement and thus the establishment of strategies for improvement based on measurable results.

In this study we present such a tool designed to help MSW Treatment and Collection Companies to evaluate the level of implementation of RE in their activities. The results obtained show high evaluation levels for the 61 measures, even though there are some variations. Measures which improve the trade-off between safety and production are of special interest and organisations should make every effort to transmit this message to senior management, line managers and front-line workers, given its importance for the implementation of RE.

We can draw a similar conclusion regarding the need for those responsible for safety to be clearly identified and for sources of help to be accessible to employees. These measures, which are apparently easier to take, have a major impact on RE. In this sense it should be remembered that the employees in MSW sector have a lower educational level than their peers in other industrial processes.

The Composite Leading Indicator would, of course, facilitate comparisons between companies or within the same company over time, thus helping management to design Benchmarking measures. This could be done individually for each of the 61 variables, for the 6 principles, for the JGV related to a particular job, or GSAR for the whole company or activity evaluated.

Also, we believe it would be interesting for future research to verify that the weighting assigned to the different principles and measures is consistent in companies in the same sector in other countries, perhaps by looking at cultures that are less closely related than those of Spain and Italy. Needless to say, we think it would be interesting to analyse and extend this model to companies in other non-industrial sectors and to apply evaluation techniques other than composite indicators.

Acknowledgements

This research forms part of the CICE SAFERA Eranet 2013 project "Design and development of a simulation tool for decision making in the management of health and safety based on resilience engineering to promote a safety culture change process in MSW treatment companies (Asses-Re-Tool)". This work was funded by the Government of Andalusia, awarded by the Department of Economy, Innovation and Science through the Agency of Innovation and Development of Andalusia and by Italian Workers' Compensation Authority (INAIL). We would like to thank Professor Saeed Shirali at the Ahvez Jundishapur University, the Spanish and Italian experts who took part in the Delphi study, LIMASA, which facilitated our participation in the project, and Universita Degli Studi Federico II di Napoli. We would also like to express our gratitude for the field work carried out by Pedro Fenoy Illacer in Spain and by Nicola Forcelli in Italy. Finally, it is also necessary to thank the Ministry of Education, Culture and Sport of the Government of Spain for its support through the "Programa de Formación del Profesorado Universitario" (FPU 16/03298).

Appendix A.

See Tables 7–13.

Table 7
Evaluation and analysis of the top management commitment principle related to RE.

Weight	Statistical analysis								Inferential analysis		
	Mean	Quartiles			RIR	%median ± 1	Confidence interval for mean: 95%		Levene	*T* test	
		25	50	75			Lower	Upper	p value	p value	Differences in means
w_{tmc1}	3.73	3.00	4.00	4.00	0.25	100.00%	3.48	3.97	.002	.164	.317
w_{tmc2}	3.36	3.00	3.00	4.00	0.33	90.91%	3.04	3.69	.305	.836	.067
w_{tmc3}	3.59	3.00	4.00	4.00	0.25	90.91%	3.24	3.94	.022	.549	.200
w_{tmc4}	2.95	3.00	3.00	3.00	0.00	90.91%	2.70	3.21	.179	.066	.450
w_{tmc5}	4.73	4.75	5.00	5.00	0.05	95.45%	4.48	4.97	.590	.584	.133
w_{tmc6}	4.05	3.75	4.00	5.00	0.31	100.00%	3.73	4.37	.137	.755	.100
w_{tmc7}	4.23	4.00	4.00	5.00	0.25	100.00%	3.99	4.46	.032	.062	−.417
w_{tmc8}	3.77	3.00	4.00	4.00	0.25	100.00%	3.44	4.11	.092	.060	.600
w_{tmc9}	3.82	3.75	4.00	4.00	0.06	100.00%	3.60	4.04	.023	.067	−.400

Table 8
Evaluation and analysis of the Just Culture principle related to RE.

Weight	Statistical analysis								Inferential analysis		
	Mean	Quartiles			RIR	%median ± 1	Confidence interval for mean: 95%		Levene	T test	
		25	50	75			Lower	Upper	p value	p value	Differences in means
w_{jc_1}	4.05	4.00	4.00	4.00	0.00	100.00%	3.79	4.30	.179	.066	−.450
w_{jc_2}	4.41	4.00	4.00	5.00	0.25	100.00%	4.19	4.63	.165	.366	−.200
w_{jc_3}	3.68	3.00	4.00	4.00	0.25	100.00%	3.47	3.89	.045	.291	.217
w_{jc_4}	4.14	4.00	4.00	5.00	0.25	100.00%	3.85	4.42	.292	.814	−.067
w_{jc_5}	3.18	3.00	3.00	4.00	0.33	90.91%	2.80	3.56	.803	.566	.217
w_{jc_6}	3.82	3.75	4.00	4.00	0.06	90.91%	3.52	4.11	.004	.056	.516
w_{jc_7}	3.68	3.75	4.00	4.00	0.06	95.45%	3.36	4.00	.023	.174	.400
w_{jc_8}	3.68	3.00	3.50	4.00	0.29	81.82%	3.34	4.03	.049	.110	−.517
w_{jc_9}	3.41	3.00	3.00	4.00	0.33	95.45%	3.15	3.67	.498	.949	−.017
$w_{jc_{10}}$	3.00	3.00	3.00	3.00	0.00	90.91%	2.69	3.31	.476	.060	.550
$w_{jc_{11}}$	3.18	3.00	3.00	4.00	0.33	95.45%	2.83	3.53	.006	.920	.033

Table 9
Evaluation and analysis of the Culture of Learning principle related to RE.

Weight	Statistical analysis								Inferential analysis		
	Mean	Quartiles			RIR	%median ± 1	Confidence interval for mean: 95%		Levene	T test	
		25	50	75			Lower	Upper	p value	p value	Differences in means
w_{cl_1}	3.82	3.75	4.00	4.00	0.06	100.00%	3.60	4.04	.079	.123	.333
w_{cl_2}	3.86	4.00	4.00	4.00	0.00	100.00%	3.66	4.07	.000	.191	.250
w_{cl_3}	4.09	4.00	4.00	5.00	0.25	100.00%	3.79	4.39	.207	.956	.017
w_{cl_4}	3.32	3.00	3.00	3.00	0.00	100.00%	3.11	3.53	.000	.040*	−.400
w_{cl_5}	4.14	4.00	4.00	4.25	0.06	100.00%	3.89	4.38	.078	.309	−.250
w_{cl_6}	3.73	3.00	4.00	4.00	0.25	95.45%	3.36	4.09	.492	.892	−.050
w_{cl_7}	3.55	3.00	3.00	4.00	0.33	86.36%	3.19	3.90	.038	.778	.100
w_{cl_8}	4.14	4.00	4.00	5.00	0.25	100.00%	3.85	4.42	.907	.681	.117
w_{cl_9}	3.77	3.00	4.00	4.00	0.25	100.00%	3.47	4.08	.068	.661	−.133
$w_{cl_{10}}$	4.00	4.00	4.00	4.25	0.06	95.45%	3.66	4.34	.265	.584	.183
$w_{cl_{11}}$	3.68	3.00	4.00	4.00	0.25	100.00%	3.47	3.89	.751	.875	.033
$w_{cl_{12}}$	3.77	3.00	4.00	4.00	0.25	100.00%	3.47	4.08	.381	.870	.050
$w_{cl_{13}}$	3.86	3.00	4.00	4.00	0.25	100.00%	3.58	4.15	.652	.284	−.300
$w_{cl_{14}}$	4.05	4.00	4.00	4.00	0.00	100.00%	3.83	4.26	.108	.207	−.267
$w_{cl_{15}}$	4.50	4.00	4.50	5.00	0.22	100.00%	4.27	4.73	.751	.095	−.367

* $p < 0.05$.

Table 10
Evaluation and analysis of the Awareness and Opacity principle related to RE.

Weight	Statistical analysis								Inferential analysis		
	Mean	Quartiles			RIR	%median ± 1	Confidence interval for mean: 95%		Levene	T test	
		25	50	75			Lower	Upper	p value	p value	Differences in means
w_{ao_1}	2.91	2.00	3.00	3.00	0.33	100.00%	2.61	3.21	.130	.010*	.717
w_{ao_2}	3.14	2.75	3.00	4.00	0.42	100.00%	2.79	3.48	.051	.133	.483
w_{ao_3}	3.77	4.00	4.00	4.00	0.00	90.91%	3.54	4.01	.000	.054	.417
w_{ao_4}	4.05	4.00	4.00	5.00	0.25	95.45%	3.70	4.39	.876	.774	.100
w_{ao_5}	3.82	3.00	4.00	4.00	0.25	100,00%	3.49	4.14	.032	.632	.150
w_{ao_6}	4.27	4.00	4.00	5.00	0.25	100.00%	4.07	4.47	.000	.007*	−.500
w_{ao_7}	4.09	4.00	4.00	4.00	0.00	100.00%	3.86	4.32	.916	.123	−.350
w_{ao_8}	3.95	4.00	4.00	4.00	0.00	100.00%	3.79	4.12	.384	.097	.267
w_{ao_9}	3.86	3.75	4.00	4.00	0.06	100,00%	3.62	4.11	.530	.069	.433
$w_{ao_{10}}$	3.95	3.75	4.00	4.25	0.13	95.45%	3.61	4.30	.107	.441	.267
$w_{ao_{11}}$	4.23	4.00	4.00	5.00	0.25	100,00%	3.96	4.50	.362	.623	.133

Table 11
Evaluation and analysis of the Preparedness principle related to RE.

Weight	Statistical analysis								Inferential analysis		
	Mean	Quartiles			RIR	%median ± 1	Confidence interval for mean: 95%		Levene	T test	
		25	50	75			Lower	Upper	p value	p value	Differences in means
w_{P1}	4.14	4.00	4.00	4.00	0.00	100.00%	3.98	4.29	.000	.082	−.250
w_{P2}	3.64	3.00	4.00	4.00	0.25	100.00%	3.42	3.85	.022	.152	.300
w_{P3}	3.50	3.00	3.50	4.00	0.29	100.00%	3.27	3.73	.881	.416	.183
w_{P4}	3.82	3.75	4.00	4.00	0.06	100.00%	3.60	4.04	.500	.881	−.033
w_{P5}	3.64	3.00	4.00	4.00	0.25	100.00%	3.38	3.89	1.000	.327	−.250
w_{P6}	3.32	3.00	3.00	4.00	0.33	100.00%	3.07	3.57	.058	.550	.150
w_{P7}	3.73	3.00	4.00	4.00	0.25	100.00%	3.45	4.01	.678	.858	−.050
w_{P8}	4.14	4.00	4.00	4.25	0.06	100.00%	3.89	4.38	.744	.789	−.067
w_{P9}	4.05	4.00	4.00	4.00	0.00	100.00%	3.83	4.26	.556	.699	−.083

Table 12
Evaluation and analysis of the Flexibility principle related to RE.

Weight	Statistical analysis								Inferential analysis		
	Mean	Quartiles			RIR	%median ± 1	Confidence interval for mean: 95%		Levene	T test	
		25	50	75			Lower	Upper	p value	p value	Differences in means
w_{f1}	4.73	4.75	5.00	5.00	0.05	95.45%	4.48	4.97	.983	.838	−.050
w_{f2}	4.45	4.00	5.00	5.00	0.20	90.91%	4.16	4.75	.896	.737	−.100
w_{f3}	4.05	3.75	4.00	5.00	0.31	95.45%	3.60	4.49	.336	.822	.100
w_{f4}	4.05	4.00	4.00	4.00	0.00	100.00%	3.79	4.30	.192	.744	−.083
w_{f5}	4.00	4.00	4.00	4.00	0.00	100.00%	3.76	4.24	.761	.437	−.183
w_{f6}	4.18	4.00	4.00	4.25	0.06	100.00%	3.96	4.40	.916	.498	−.150

Table 13
Evaluation and analysis of RE principles.

Weight	Statistical analysis								Inferential analysis		
	Mean	Quartiles			RIR	%median ± 1	Confidence interval for mean: 95%		Levene	T test	
		25	50	75			Lower	Upper	p value	p value	Differences in means
W_{TMC}	4.55	4.00	5.00	5.00	0.20	100.00%	4.32	4.77	.616	.712	−.083
W_{JC}	4.09	3.75	4.00	5.00	0.31	100.00%	3.76	4.42	.153	.616	−.167
W_{CL}	3.91	4.00	4.00	4.00	0.00	100.00%	3.72	4.10	.000	.343	−.200
W_{AO}	4.00	4.00	4.00	4.00	0.00	100.00%	3.73	4.27	.613	.501	−.183
W_{P}	4.18	4.00	4.00	4.00	0.00	100.00%	4.01	4.36	.000	.039	−.333
W_{F}	4.00	4.00	4.00	4.00	0.00	100.00%	3.76	4.24	.508	1.000	0.000

$^{*}p < 0.05$.

Appendix B. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ssci.2018.04.014.

References

Achard, P.O., Agnello, P., Bragatto, P.A., Fabbricino, M., 2016. Assessment of Resilience in MSW Management Companies. J. Solid Waste Technol. Manage. 42 (1), 10–20.
Costella, M.F., Saurin, T.A., de Macedo Guimarães, L.B., 2009. A method for assessing health and safety management systems from the resilience engineering perspective. Safety Sci. 47 (8), 1056–1067.
Domínguez Serrano, M., Blancas Peral, F., Guerrero Casas, F., González Lozano, M., 2011. Una revisión crítica para la construcción de indicadores sintéticos. Revista de Métodos Cuantitativos para la Economía y la Empresa 11, 41–70.
Gordon, T.J., 1994. The Delphi Method. AC/UNU Millennium Project. Futures Res. Methodol. 1–9.
Grabowski, M., Ayyalasomayajula, P., Merrick, J., Mccafferty, D., 2007. Accident precursors and safety nets: leading indicators of tanker operations safety. Maritime Policy & Manag. 34 (5), 405–425.
Grecco, C.H., Vidal, M.C., Santos, I.J., Carvalho, P.V., 2012. A method to assess safety and resilience in radiopharmaceuticals production process. Work 41 (Supplement 1), 5839–5843.
Häkkinen, K., 1995. A learning-by-doing strategy to improve top management involvement in safety. Safety Sci. 20 (2–3), 299–304.
Hinze, J., Thurman, S., Wehle, A., 2013. Leading indicators of construction safety performance. Safety Sci. 51 (1), 23–28.
Herrera, I.A., Tinmannsvik, R.K., 2006. Key elements to avoid drifting out of the safety space. In: Proceedings of the second resilience engineering symposium. Juan-Les-Pins, France.
Herrera, I.A., Hovden, J., 2008, October. Leading indicators applied to maintenance in the framework of resilience engineering: a conceptual approach. In: Paper presented at The 3rd Resilience Engineering Symposium (Vol. 28, p. 30).
Hollnagel, E., Woods, D.D., Leveson, N., 2007. Resilience engineering: Concepts and precepts. Ashgate Publishing, Ltd.
Huber, S., van Wijgerden, I., de Witt, A., Dekker, S.W., 2009. Learning from organizational incidents: resilience engineering for high-risk process environments. Process Safety Prog. 28 (1), 90–95.

Junta de Andalucía, 2011. Condiciones de trabajo y gestión preventiva en las empresas de residuos sólidos urbanos en Andalucía. Consejería de Empleo. Instituto Andaluz de Prevención de Riesgos Laborales, retrieved from < http://www.juntadeandalucia.es/export/drupaljda/1_2146_informe_rsu.pdf > on 28th July 2015.

Landeta Rodríguez, J., 2002. El método Delphi: una técnica de previsión del futuro. Ariel, Barcelona.

Lay, E., Branlat, M., Woods, Z., 2015. A practitioner's experiences operationalizing Resilience Engineering. Reliab. Eng. Syst. Safety 141, 63–73.

Le Coze, J.C., 2013. New models for new times. An anti-dualist move. Safety Sci. 59, 200–218.

León, O.G., Montero, I., 2003. Métodos de investigación en psicología y educación (No. 303.42). McGraw-Hill Interamericana.

Madni, A.M., Jackson, S., 2009. Towards a conceptual framework for resilience engineering. IEEE Syst. J. 3 (2), 181–191.

Malla, F.G., Zabala, I., 1978. Previsión del futuro en la empresa: el método Delphi. Estudios Empresariales 39, 13–24.

Manuele, F.A., 2009. Leading & lagging indicators. Profess. Safety 54 (12), 28.

Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffman, A., Giovannini, E., 2005. Handbook on constructing composite indicators.

Mengolini, A., Debarberis, L., 2008. Effectiveness evaluation methodology for safety processes to enhance organisational culture in hazardous installations. J. Hazard. Mater. 155 (1–2), 243–252.

Øien, K., Utne, I.B., Herrera, I.A., 2011a. Building safety indicators: Part 1–theoretical foundation. Safety Sci. 49 (2), 148–161.

Øien, K., Utne, I.B., Tinmannsvik, R.K., Massaiu, S., 2011b. Building safety indicators: Part 2–application, practices and results. Safety Sci. 49 (2), 162–171.

Righi, A.W., Saurin, T.A., Wachs, P., 2015. A systematic literature review of resilience engineering: research areas and a research agenda proposal. Reliab. Eng. Syst. Safety 141, 142–152.

Rubio-Romero, J., Molinillo, S., López-Arquillos, A., Arjona-Jiménez, R., de la Varga-Salto, J.M., 2018. Comparative study of resilience engineering in solid waste treatment plants: a case study in two European cities. WORK: J. Prevent., Assessment Rehabilitat (in press).

Saurin, T.A., Formoso, C.T., Cambraia, F.B., 2008. An analysis of construction safety best practices from a cognitive systems engineering perspective. Safety Sci. 46 (8), 1169–1183.

Saurin, T.A., Júnior, G.C.C., 2011. Evaluation and improvement of a method for assessing HSMS from the resilience engineering perspective: a case study of an electricity distributor. Safety Sci. 49 (2), 355–368.

Saurin, T.A., Formoso, C.T., Famá, C., 2014. Criteria for assessing safety performance measurement systems: insights from resilience engineering. Resilience Eng. Practice: Becoming Resilient 2, 63–78.

Shirali, G.A., Mohammadfam, I., Ebrahimipour, V., 2013. A new method for quantitative assessment of resilience engineering by PCA and NT approach: a case study in a process industry. Reliab. Eng. Syst. Safety 119, 88–94.

Toellner, J., 2001. Improving safety & health performance: identifying & measuring leading indicators. Profess. Safety 46 (9), 42.

Ugwu, O.O., Kumaraswamy, M.M., Wong, A., Ng, S.T., 2006. Sustainability appraisal in infrastructure projects (SUSAIP): Part 1. Development of indicators and computational methods. Automat. Construct. 15 (2), 239–251.

Woods, D., Herrera, I., Branlat, M., Woltjer, R., 2013. Identifying imbalances in a portfolio of safety metrics: the q4-balance framework for economy-safety tradeoffs. In: Proceedings of the fifth resilience engineering symposium. Soesterberg, Nether-lands.

Woods, D.D., 2015. Four concepts for resilience and the implications for the future of resilience engineering. Reliab. Eng. Syst. Saf. 141, 5–9.

Wreathall, J., 2006. Properties of resilient organizations: an initial view. In: Resilience engineering: Concepts and precepts. Ashgate, Aldershot, UK, pp. 275–286.