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Improving performance evaluation of health, safety and environment management system by combining fuzzy cognitive maps and relative degree analysis

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ABSTRACT

The performance evaluation of health, safety and environment management system (HSE-MS) is considered to be an effective way to eliminate out dated measures and help managers adopt proper rectification measures. The objective of this paper is to design a weight distribution model for HSE-MS performance evaluation, the importance of which stems from the current lack of integrated approaches for interpreting and ranking HSE-MS performance evaluation elements. Initially, Fuzzy Cognitive Maps (FCM) is adopted to illustrate the direct and indirect effects of HSE-MS elements on system performance indicators, and the results of FCM are used to develop leading factors helpful for decision making in an intensive management system. Then, the weight distribution from FCM is amended by Relative Degree Analysis (RDA), the aim of which is to combine the advantages of quantitative and qualitative knowledge-driven methods. Finally, the level of HSE-MS performance is obtained and analyzed. The whole performance evaluation framework highlights the potential correlations of evaluation elements as well as expert opinions, which will improve the reasonability of the HSE-MS performance evaluation.

1. Introduction

Health, Safety, Environment Management Systems (HSE-MS) is an integrated assistant tool composed of several factors such as organization framework, management task and operation specification. These factors form a structured management system through scientific fusion to eliminate injuries, adverse health effects and damages to the environment. From a functional perspective, its main objective is to conduct an advanced risk analysis to identify the hazardous consequences and consequently to hammer out appropriate loss control measures. Therefore, HSE-MS is considered to contribute to the profitability of the industry and it is broadly adopted by modern enterprises. HSE-MS in different fields is varied due to the unique characteristics of different industries. The specific requirements for constructing HSE-MS can refer to standards such as OHSAS18001 and ISO14000 (Abad et al., 2013; Gholami et al., 2015).

To ensure HSE-MS effective implementation, HSE-MS performance evaluation is carried out, which is conducted by an expert panel composed of relevance engineers, academic researchers, site operators and managers. Since HSE-MS performance evaluation can regulate, standardize and optimize HSE-MS in a proper manner, and timely eliminate out dated measures in management systems as well as continuously improve the performance of the enterprises, researches on HSE-MS performance evaluation are increasing during the last two decades. International Safety Rating System (ISRS) developed and first introduced in 1978 by Frank Bird is a widely used method to do HSE-MS performance evaluation, where experts are trained as auditors, and specially certified ISRS personnel will visit the sites and award one to five "stars" for safety performance at the site (Guastello, 1991). It can provide considerable benefits by addressing good or bad practices according to scores awarded by experts. However, a significant drawback of ISRS is lack of interrelationship reasoning metric among the evaluating factors, which could bring about inefficient and pointless workload. Considering that evaluating the performance of HSE-MS is not a simple exercise as a variety of variables are involved, many research work have been devoted to get a more scientific and reasonable evaluation result. The interrelationships of occupational health and safety, environment impacts and public satisfaction are well investigated (Azadeh et al., 2015) which proves that the elements of HSE-MS have specific correlative relation with each other. Shikdar

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et al. (2003) had also reported that a significant correlation exists among productivity indicators and health and organizational attributes. These inspires that certain elements of HSE-MS may significantly influence the overall performance and therefore must be considered and designed with more attention. A quantitative comparison analysis of strategy management models, with the purpose to screen better contractors according to their HSE-MS performance, is proposed based on accepted international standards within the framework of management Deming cycle (Abbaspour et al., 2012). This model provides quantitative evaluation measures of HSE-MS performance as a percentage of an ideal level with maximum possible score for each attribute. For improving the accuracy of information fusion, a model was developed to evaluate the maintenance performance using an analytical hierarchy process in ranking the weightings of the criteria set (Shen et al., 1998). Fuzzy Cognitive Maps (FCM) was first described by Bart Kosko in 1986. Recently an increasing number of publications are devoted to applications of FCM across a variety of fields, such as business planning, medicine, and environmental management. Relative Degree Analysis (RDA) aims to discover the correlation characters existing in big data to find out the rules of how the changes of some events cause the changes of the others. Quantitative model based on RDA constantly spring up. Lin et al. (2007) used grey relation analysis to explore the inter-relationships among different industrial sectors in Taiwan in order to provide an insight regarding sustainable development policy making. Asadzadeh et al. (2013) adopted FCM to analyze the integrated health, safety, environment (HSE) and ergonomics (HSEE). Through the integrated modeling for assessment of HSE-MS related elements with multi-path influences on workers' productivity, injury rate and satisfaction, it gives contributions to the solution of increasing problems associated with complex dynamical systems.

One of challenges of implementing HSE-MS performance evaluation is that, HSE-MS covers a broad range of programs ranging from human factors to work regulation, negotiation, organization and system design in macro-level, and in micro-level, each factor concerns with its underlying elements, in this sense, the HSE-MS elements have mass connecting metrics, and each element may have certain influence on the system performance as well as other elements. Thus the performance evaluation of HSE-MS should be a structured, and a well designed and integrated approach with respect to the insights of the complexity of HSE-MS elements is imperative Two key issues in system performance evaluation is that, one is the identification of evaluation score or description for each individual element, which displays the local performance of the system, and another one is to determine weight distribution, which represents the organization mechanism of local performances to reflect the holistic system performance. Since most HSE-MS performance evaluations depend on the scores given by expert opinions, and these scores are subjective, open and understood, exploring a deep view of weight distributions in evaluation system may give insight into illustrating the system performances. Therefore, it is required to investigate HSE-MS inner causal relationships to make the performance evaluation more oriented and pertinent.

This paper aims to: (i) develop a methodology reference framework for HSE-MS performance evaluation with the weight distribution of HSE-MS elements; and (ii) identify the causal ranks of HSE-MS elements to illustrate different influence levels on the sub-performance of job satisfaction, stuff productivity and society reputation as well as the over system performance. The proposed understanding of this allows enterprises with limited time and resources to prioritize their improvement measures and daily focuses. In addition, the research on weight distribution provides a more scientific and reasonable way to synthesize of experts' opinions.

2. The proposed methodology

The proposed methodology is based on the framework as shown in Fig. 1. Initially, the experts compare each item of the practical conditions in enterprises with the HSE-MS requirements mainly based on field investigations, face to face interviews and historical records. The better the evaluation item fits with the HSE-MS requirement, the higher score the evaluation item obtains (Step 1 and Step 2). Then, after each evaluation item score is obtained, the expert panel will assign a weight distribution representing how important the element is relative to the other element and to the whole system (Step 3). Following that ultimate evaluation score, the holistic HSE-MS performance can be calculated in many ways (Step 4). Finally, the outcome of the calculations could describe HSE-MS performance from expected perspectives. Various ranking methods are used to illustrate whether the HSE-MS is up to the standard (Step 5). It should be noted that the qualitative analysis is to afford foundations for quantitative calculation and limit the weight distribution to a reasonable level.

This paper mainly devotes to the research of Step 3 (marked red[1] color in Fig. 1) exploring the inner causal paths between HSE-MS elements, which could contribute to identify key elements that play vital roles on the consequences. Meanwhile, for the issue of weight distribution, comprising huge and interrelated detailed aspects of the HSE-MS elements, too objective or subjective deficiency of weight distribution of evaluation elements may result in an unbearable deviation to the whole system performance. Given that improving the weight distribution model is valuable.

Since it is a complex process to assign weights for evaluation elements based on experts' opinions, combing qualitative and quantitative approaches is a workable way to well integrate experiential knowledge, statistical data and computational technology. So FCM is employed to determine the weight distribution from the qualitative perspective owing to its excellent logical inference function, and RDA, owing to its simplicity and practicality, is adopted to supply necessary numerical correction for FCM from the quantitative perspective. This weight distribution model based on FCM–RDA includes 8 steps as following:

Step 1: A credibility weight is set for each of the P experts.
Step 2: Every expert is asked to make descriptions and comments on each of the N concept nodes.
Step 3: For each pair of concepts Ci and Cj, each expert is asked to use the If-Then rules to assign linguistic weights for the evaluating concepts. The If-Then rules are stated as following.
IF Ci change
THEN causes value of concept Cj change
THUS the influence of concept Ci on concept Cj is Weight (Ci, Cj)
Step 4: Select the comment sets of concept nodes to construct the FCM. The overall linguistic weight for each concept focuses on all direct and indirect paths.
Step 5: If quantitative data are available, RDA method is implemented into the data set to derive the correlation degree of concept nodes.
Step 6: Aggregate these linguistic weights and then some conflicting evaluating results for the concepts draw our special attention. Go back to the FCM mode and review causal paths among the arcs connecting conflicting concepts.
Step 7: Analyze the generated conflicting evaluating results based on historical records, managers' communications or field inspections. The credibility weight of experts is adjusted by the corresponding credibility weight.

[1] For interpretation of color in Figs. 1 and 6, the reader is referred to the web version of this article.