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A novel approach for enhancing green supply chain management using converged interval-valued triangular fuzzy numbers-grey relation analysis

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ABSTRACT

The existing literatures are lacking on the cost and benefit concerns, screening the measures and convergence of interval-valued triangular fuzzy numbers-grey relation analysis (IVTFN-GRA) weight together. Nonetheless, Green supply chain management is always suffering the linguistic preferences and system incomplete information in evaluation process to enhance the performance. Yet, those previous studies are merely based on un-converged weight results. Hence, this study proposed a hybrid method to dealing with this multi-criteria evaluation problem. Fuzzy Delphi method proposes to screen the evaluation criteria and converged IVTFN-GRA weight method handles the vagueness system uncertainty and incomplete information with interdependence relations. Hence, the proposed hybrid method enhanced the green supply chain management and compared multi-methods to enhance their performance in Taiwanese electronic focal firm. The result showed that the converged weight is consistent with the real practices, despite the differences with the current average weighting method. The finding in the long-term perspective: resilience and operational improvement are the top weighted aspects.

1. Introduction

Green supply chain management (GSCM) is well-practiced by manufacturing firms in Taiwan as well as their supply chain networks. Now, manufacturers have reduced the harm to the natural environment when generating waste, disrupting the ecosystem and depleting natural resources. However, firms are still reluctant, or not effective, when implementing aspects of GSCM practices in the operations (Zhu et al., 2008; Wu et al., 2015). In a recent study, Olugu and Wong (2012) proposed that a suitable expert fuzzy rule-based, evaluation system is crucial for achieving a successful closed-loop supply chain in the automotive industry. Tseng and Chiu (2013) proposed using fuzzy- grey relation analysis (GRA) in choosing the suitable supplier as a key strategy in eliminating environmental impact when using GSCM to improve a firm's performance. Tseng et al. (2014a,b) proposed the application of cost and benefit concerns on hybrid multi-criteria decision making (MCDM) to assist in the process of analyzing and selecting the alternatives aligned with the proposed criteria on both the qualitative and quantitative scales. However, as prior studies have shown, the consideration of MCDM results in the development of the GSCM in the decision-making process. Still, the main concern is that the literature neglects to include the cost and benefit concerns, screening the measures and convergence weight in the decision-making process. Moreover, the literature has not explained how to screen and validate the evaluation criteria and converged weights.

GSCM refers to a variety of methods and practices that firms can use enhance and retain performance within their products or processes. It has been considered as an approach to simultaneously deal with environment and economic concerns between suppliers and customers (Wu et al., 2015). Several studies investigated the relationship between GSCM and performance in order to explore the critical drivers for developing sustainability. For instance, Zhu et al. (2008) proposed environmental management, green purchasing, eco-design, environmental cooperation with customers

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and investment recovery to establish a model to evaluate performance. To confirm the performance of these practices, Jabbour et al. (2015) set 13 measures under environmental and operational performance to identify its potential relationships with GSCM. Furthermore, Malviya and Kant (2016) adopted strategic, organization, social-culture, buyer-supplier, legislation and technical enablers to measure the implementation of GSCM. Luthra et al. (2015) utilized critical success factors to develop GSCM structure in developing sustainability. GSCM studies continuously explore and validate measures for use in evaluating the performance of GSCM practices. Appropriate measurements aid in determining the critical drivers of GSCM, and these measurements can practically reflect the real situation of Taiwanese electronic manufacturing firms. To support the gap in measuring performance, MCDM enables to structure a logical and systematical model in reducing the complexity for enhancing the performance.

The MCDM method is a widely used approach for evaluating typical multiple-related criteria. In practice, qualitative and quantitative measures are used for determining the criteria performance, with respect to the criteria, and the relative importance of the evaluation criteria. Tseng and Chiu (2013) proposed choosing the suitable supplier as a key strategy in eliminating environmental impact on GSCM using a fuzzy-grey relation analysis system to improve the firm's performance. Tadic et al. (2014) proposed selecting the best alternative using a complex hybrid decision making method, which consists of conflicting and uncertain elements when solving the logistics problems. Rabbani et al. (2014) applied a branch of the MCDM technique and a sustainability balance scorecard to evaluate the performance of firms that helped authorities toward achieving a competitive advantage. However, there are many related decision-making methodologies applied to the task of organizing and analyzing complex measures subject to uncertainties (Li et al., 2007; Wang and Chang, 2007; Tseng et al., 2014a,b). The main advantages of these methods are their inherent ability to handle intangibles and less cumbersome mathematical calculations. Prior studies have applied MCDM methods with fuzzy sets to address uncertainty and overcome the vagueness of existing methods. Fuzzy sets and triangular fuzzy numbers (TFN) are often applied to express linguistic variables in studies (Cakir and Canbolat, 2008; Tseng and Chiu, 2013; Ren and Sovacool, 2014; Tseng et al., 2014a,b), whereas fuzzy set theory and MCDM have been useful in other researches (Ghorbani et al., 2013; Hague et al., 2015; Kahraman et al., 2010). However, decision-making process requires establishing interdependence relations among the measures, which has not been addressed in these recent studies. The IVTFN, GRA and converged weight methods are proposed to support interdependence relations and in consideration of the incomplete analytical information available.

Moreover, GRA has been successfully applied in diverse applications to address the incomplete system information. Wang et al. (2004) further applied the grey relation to the process evaluation in assigning rankings and scores to performances. Tseng (2009) used a solution based on a combined Grey-fuzzy making trial and evaluation laboratory method to address service quality expectation ranking with uncertainty. In addition, Tseng (2009) presented a perception approach to address supplier evaluation of environmental knowledge management capacities with uncertainty and incomplete information. Wang (2014) applied GRA and fuzzy techniques for order preference by similarity to ideal solutions to partition financial ratios into several clusters and to find representative indices from the clusters and then presented the evaluation criteria in a financial assessment of a Taiwan container shipping firm. The GRA is effective in evaluating and weighing the key criteria with limited information (Zhai et al., 2009; Tsai et al., 2012). However, prior studies rarely deliberated the cost and benefit concerns and converged weight method.

Therefore, the reason for applying TFN is ease of use in information processing and computational simplicity in linguistic preferences (Tseng, 2008; Wang et al., 2009). The values' range is relatively easy to determine. It is appropriate to define lower and upper bound values as interval value triangular fuzzy numbers (IVTFN) (Zhang and Liu, 2011). Still, the decision-making process needs to address the information incomplete in the analytical system. Hence, GRA aims to express the system information more precisely (Deng, 1989; Tseng, 2008). The study of Ashtiani et al. (2009) developed an interval-valued fuzzy weighting method to solve MCDM problems in which the rating values and the weights of criteria are linguistics terms, which can be expressed in IVTFN. Zhang et al. (2011) developed an extended GRA method for solving MCDM problems with unknown criterion weights. Wu et al. (2016) applied IVTFN associated with grey relational analysis to improve the insufficient information, cost and benefit concerns and overcome the incomplete system under uncertainties in sustainable supply chain management study. Nevertheless, the comparisons of multi-method with and without cost and benefit concerns involved in the analytical system are lacking. Still, the shortcoming of these previous studies is failed to involve converged weight method in the analytical result. Hence, the converged IVTFN-GRA is proposed.

To screen and validate the measures, the fuzzy Delphi method (FDM) has been proposed (Murray et al., 1985; Chang et al., 2011). Hence, the purpose of this study is to validate the measures and address the linguistic expressions, incomplete system information, cost and benefit concerns and converged weight method of the GSCM assessment. The objective of this study is to extract and analyze the GSCM attributes with the proposed FDM, compared multi-methods with or without cost and benefit concerns and lastly, the converged IVTFN-GRA to determine management priority. Such a proposed method can assist the firm in decision-making and in comparing similar methods that critically influence the decision-making of the firms' management. To demonstrate the effectiveness of the developed proposed method in facilitating the evaluation process, this study conducted on focal electronic manufacturing firms that implemented GSCM for past years.

The study's contribution is threefold: (1) using FDM to determine the GSCM measures; (2) verifying and comparing the usefulness of proposed IVTFN-GRA with and without cost and benefit concerns and weighted average method; and (3) acquiring the important GSCM attributes in the industrial practices. The rest of this paper is organized as follows: Section 2 describes FDM, the converged weight method of IVTFN-GRA and proposed approach; Section 3 presents a case study to demonstrate the feasibility and consistency of the extended proposed method; Section 4 applies to managerial implications in this study. Finally, the conclusions are discussed.

2. Methods

This section proposes a solutions method to address how the proposed traditional GRA, IVTFN-GRA with and without cost and benefit concerns method, performs the GSCM in the operations.

2.1. Fuzzy delphi method

Murray et al. (1985) proposed to integrate the Delphi method and fuzzy sets together involve at least two reviews by subject-matter experts on the criteria. Kuo and Chen (2008) applied FDM to construct key appraisal indicators for mobility of the service industries. Hence, FDM screens the criteria in the first stage as this method can address the fuzziness of the common understanding of expert opinions and allow for evaluation on a more flexible scale. A fuzzy set, $\tilde{A}$, in a universe of discourse, X, is characterized

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