Ann Oper Res (2016) 238:615–635
DOI 10.1007/s10479-015-2067-2

Extension of grey relational analysis for facilitating group consensus to oil spill emergency management

Wenshuai Wu[2] · **Yi Peng**[1]

Published online: 26 November 2015

Abstract Emergency management with oil spill is a very complex decision problem. This paper targets efforts to propose and develop a new technology: an extension of grey relational analysis for facilitating group consensus model to deal with this problem. In this model, firstly, two parts of the extension of grey relational analysis are presented and proposed. One is to simultaneously compute grey relational degree to positive reference sequence (PRS) and negative reference sequence (NRS), on the basis of the basic concept of a relative closeness degree of TOPSIS. The other is to determine index weights by a developed mathematical optimization model implemented by Matlab 2012a, which also matches the basic concept of the first part of the extension. Secondly, a group consensus facilitation method based on three-dimension leg-mark selected location method is proposed to aggregate individual preferences in order to address the problem of ranking inconsistency during the evaluation of multi-criteria decision making methods. What's more, the calculation steps and processes of n-dimension leg-mark selected location method for facilitating group consensus are given and explored. A simulation case study on oil spill emergency management demonstrates and verifies the feasibility and effectiveness of our proposed model by comparative analysis with the previous research papers.

Keywords Decision analysis · Group consensus · MCDM · Emergency management

✉ Yi Peng
pengyicd@gmail.com

Wenshuai Wu
fhylwsw@163.com

1 School of Management and Economics, University of Electronic Science and Technology of China, Chengdu 611731, China

2 School of Economics and Management, East China Jiaotong University, Nanchang 330013, Jiangxi, China

1 Introduction

During the past 20–30 years, the frequent occurrence of emergencies with oil spill in all over the world have caused a large number of environmental pollution, ecological damages, property losses and casualties, such as Exxon Valdez oil spill of the United States in 1989, Sea Empress oil spill of Britain in 1996, Erika tanker accident of France in 1999, prestige oil spill of Spain in 2002, oil spill of the Russian Arctic in 2007, Gulf of Mexico oil spill of the United States in 2010, Dalian oil spill of China in 2010, Bohai Bay oil spill of China in 2011, Alberta oil spill of Canada in 2012, marine oil spill of Thailand in 2013 and Texas oil spill of the United States in 2014. The oil spill emergency management has become a focus of global concern (Anaya-Arenas et al. 2014), and it has challenged all kinds of prevention, resistance, response, mitigation and recovery capacities of fishermen, policy makers, environmentalists and all the stakeholders. How to effectively evaluate and deal with oil spill emergencies has became a worldwide highly challenging task and issue.

These accidental oil spill emergencies have also promoted and stimulated the development of new techniques to deal with oil pollution both at marine areas and shorelines (Michel et al. 2013; Passosa et al. 2014), which include chemical methods such as dispersant, mechanical methods such as skimmer and biological methods such as straw or plant material as an absorbent for oil. The biological methods have already become the focus and goal of contemporary attention and research (Swannell et al. 1996). For example, the technique of the addition of materials to encourage microbiological biodegradation of oil, known as bioremediation, has received the great attention and speculation, specifically after the emergency with Exxon Valdez oil spill of the United States (Swannell et al. 1996). However, their effectiveness can be constrained because of all kinds of possible accident scenarios companied with the sharp increase of petroleum production and petroleum transportation (Liu and Wirtz 2007a).

A golden standard of emergency management with oil spill is to minimize the loss and damage by making emergency preplan to deal with the emergency situations (Keramitsoglou et al. 2003; Krohling and Campanharo 2011). However, the design and development of the best emergency preplan are very hard to be accomplished since it is accompanied by some variable conditions such as types of oil spill, volume of oil spill, rate of oil flowing, location of oil spill, time, weather situation and the dynamic ocean environment, which can be identified as an MCDM problem (Dyer et al. 1992; Goni et al. 2015). In this paper, grey relational analysis (GRA), one of known MCDM technologies, is applied to deal with the oil spill emergency management problems of dynamic and variable factors, because GRA is a portion of grey system theory based on grey space, proposed and developed by Deng (1982), and the advantage of GRA can address complex real-world problems marked by vague, incomplete and inaccurate information (Chen and Tzeng 2004), Besides it only requires small sample data, and simple calculation.

In this paper, in order to increase evaluation accuracy of GRA for enhancing oil spill emergency management level, an extension of GRA model is developed. In this model, the extension contains two parts: The first part is to simultaneously calculate the grey relational degree to PRS and NRS, on the basis of a relative closeness degree of TOPSIS, and the second part is to determine the information of index weights by a developed mathematical optimization model which also presents the basic concept of a relative closeness degree that the most satisfactory alternative should have the nearest distance to PRS and the farthest distance to NRS, that is to say, the information of index weights matches the basic concept of the first part of the extension.

In case of response to emergency management with oil spill, many departments, organizations or institutions, such as the fishermen, policy makers and environmentalists should be considered to reflect their own benefit, interests and preferences (Krohling and Rigo 2009). In general, it will get inevitably contradictory and conflict when evaluating the best emergency preplan, especially among multi-stakeholders (Krohling and Campanharo 2011). So, the process to achieve a group consensus involves a decision process with multiple criteria and multiple stakeholders. In this background, a group consensus facilitation method is developed and proposed to address the problem of ranking inconsistency in the evaluation of MCDM. Xie et al. (2009) used two-dimension leg-mark selected location method to slope treatment for group decision making (GDM). In our method, three-dimensional Euclidean space is applied to support and develop our three-dimension leg-mark selected location method for GDM. In addition, the calculation steps and processes of n-dimension leg-mark selected location method for facilitating group consensus of n decision-makers are developed and explored in this paper.

This paper aims to illustrate and explain, in case of oil spill emergency management, how decision-making process and negotiation process are centralized in a scenario simulation framework. The focused question is that our proposed model suffices to provide feasible and effective decision support in oil spill emergency management by selecting appropriate emergency plan. Given all that, this paper proposes and develops an extension of grey relational analysis for facilitating group consensus model to oil spill emergency management involving multi-criteria, complex dynamic environments and benefits and interests of multi-stakeholders. The oil spill emergency alternatives and data have been simulated by a scenario simulation model called OSCAR (Oil Spill Contingency and Response). And in the empirical study, by comparative analysis, the research results are consistent with the previous ones from two related papers (Liu and Wirtz 2007a, b).

The remaining structures of the article are arranged: In Sect. 2, the related works are described. Section 3 demonstrates some preliminaries and foundations of GRA, TOPSIS and a three-dimension leg-mark selected location method. Next, in Sect. 4, an extension grey relational analysis for facilitating group consensus model is proposed and developed. In Sect. 5, an empirical study on emergency plan evaluation with oil spill is conducted to verify our proposed model. Finally, in Sect. 6, the conclusion is discussed.

2 Related works

The aim of emergency management oil spill is to minimize the loss and damage by making emergency preplan to deal with the emergency situations (Liu and Wirtz 2006). The traditional techniques to deal with oil spill emergencies include chemical methods such as dispersant, mechanical methods such as skimmer and biological methods such as straw or plant material as an absorbent for oil. In the recent decade, a number of studies of oil spill emergency have been conducted and some new techniques have been promoted and stimulated. Belardo et al. (1984) applied a partial set covering method to address the oil spill response equipment location problem for maritime oil spills. Psamftis and Ziogas (1985) formulated a tactical decision algorithm in the resource allocation about oil spill cleanup equipment. Psamftis et al. (1986) developed a mixed integer programming model for addressing the location problem of types and levels of cleanup capability. Bragg et al. (1994) developed a new interpretative method to evaluate bioremediation capability for oil spills on dynamic heterogeneous marine shorelines. Keramitsoglou et al. (2003) proposed developed a complete decision support system to manage marine pollution events caused by oil spills. Wirtz et al. (2004) applied a straightforward weighted sum model to deal with the problem of contingency with oil spill. Liu and Wirtz (2007a) formulated a second order fuzzy comprehensive evaluation model to evaluate and select oil spill contingency options. Liu and Wirtz (2007b) further applied the second order fuzzy comprehensive evaluation model to evaluate oil spill response planning for a group consensus decision-making. Ivanova (2011) developed an initial attempt to summarize the private and public organizations or institutions involved in addressing the oil spill problem in the Murmansk region. Liao et al. (2012) integrated genetic algorithm, case-based reasoning and artificial neural network method for dealing with oil spill accidents. Park et al. (2013) presented the National Interstate Economic Model to estimate direct, indirect and induced economic losses. MacKenzie et al. (2014) presented necessary conditions for optimality for developing a static model and a deterministic branch-and-bound algorithm for developing a dynamic model to the Deepwater Horizon oil spill in order to analyze adverse effects in the Gulf region. Helle et al. (2015) based on bayesian network, proposed a probabilistic method to analyze and manage oil spill emergency under an uncertainty environment.

Tufekci and Wallace (1998) said emergency management is essentially a very complex multiple criteria optimization problem. Emergency decision, such as oil spill in the sea, is an extremely complex multiple criteria optimization problem involving several dynamic and variable factors (Liu and Wirtz 2007a), which cannot be solved well by the traditional decision theory. MCDM methods are a series of decision-making analysis methods, evolved as an important field of operations research which pay attention to multiple and conflicting criteria (Keeney and Raiffa 1976; Wallenius et al. 2008; Kou et al. 2011; Peng et al. 2011a, b; Wu et al. 2012a; Peng and Yu 2014).

TOPSIS, as one classic technology of MCDM technologies, was initially proposed by Hwang and Yoon (1981), in order to evaluate alternative performance according to the distance to ideal solution. TOPSIS can find the most satisfactory alternative by the basic principle of having the nearest distance to the positive ideal solution (PIS) and the farthest distance to the negative ideal solution (NIS) (Chen and Hwang 1992). GRA, as one typical technology of MCDM technologies, is a multi-factor analysis tool to indicate and measure the similarity in order to analyze uncertain relations between the alternative series and the reference series (Deng 1982, 1988; Lai et al. 2005). The alternative, which is the closest to the reference series, can be considered as the best chosen alternative (Huang et al. 2008; Hamzaçebi and Pekkaya 2011). This paper, on the basis of the basic principle of TOPSIS, combines TOPSIS and GRA to derive the ranking of all the evaluation alternatives by simultaneously computing the grey relational degree to PRS and NRS. Besides, the information of index weights is determined by a mathematical optimization model which presents the extension principle of GRA that the most satisfactory alternative should minimize the distance to PRS and maximize the distance to NRS. The details are introduced in Sect. 4.

Once oil spill emergency occurs, their own benefit and interests of many departments, organizations or institutions such as the fishermen, policy makers and environmentalists should be considered, simultaneously, public demand for stricter environmental laws and environmental responsibility should be also considered. In general, it will get inevitably contradictory and conflict when evaluating the best emergency preplan involving the benefits and interests of multi-stakeholders (Krohling and Campanharo 2011). In this condition, the process to achieve a group consensus involves a decision process with multiple criteria and multiple stakeholders (Krohling and Rigo 2009). Although some favorable assessment technologies are promoted and developed (Wirtz et al. 2004; Liu and Wirtz 2007a; Liao et al. 2012), there is very difficult to reach a consensus among the organizations or stakeholders charged with responding to emergency management with oil spill. And in an MCDM problem, the essence is how to effectively aggregate individual preferences in a group consensus to solve the problem of ranking inconsistency. So, in this paper, a group consensus facilitation method, on the basis of three-dimension leg-mark selected location method, is proposed and developed to increase the overall satisfaction level for the ultimate decision-making among the multiple stakeholders for extending the aggregation method.

Two-dimension leg-mark selected location method, on the basis of expert prioritization, is to establish a two-dimensional leg-mark coordinate system for GDM where the group members consists of two people (Xie et al. 2009). It is characterized by briefness, concision and simple calculation, and it requires a little information, just individual preference ranking of each expert. Given all that, in this paper, on the basis of the two-dimension leg-mark selected location method, we first propose and develop three-dimension leg-mark selected location method to facilitate group consensus by depending on a three-dimensional leg-mark coordinate system. Then, the steps and processes of n-dimension leg-mark selected location method for facilitating group consensus are presented and given in this paper, which popularizes and improves the graphical representation of GDM in the coordinate system.

Emergency management with oil spill is an extremely complex multiple criteria optimization problem. It is very difficult to deal with those ever-variable factors and opinions of the stakeholders. For addressing such an extremely complex multi-criteria optimization problem, the paper aims to develop and propose an extension of grey relational analysis for facilitating group consensus model into group decision support system for emergency management with oil spill.

3 Preliminaries

MCDM is a popular research direction of operations research which is committed to the implementation and development of decision-making methods in order to address ill-structured decision problems by which concerns about multi-criteria, multi-objective or multi-goal of conflicting nature (Turskis and Zavadskas 2011; Kou et al. 2012, 2014b; Wu et al. 2012b; Kou and Lin 2014a; Kau et al. 2014c; Kou and Wu 2014). It covers all aspects of the decision making process. However, the increasing complexity nature of decision-making problems makes it difficult for a decision-maker to premeditate all the related aspects of the real-world applications (Vahdani et al. 2013). So in this paper, on the basis of TOPSIS and GRA, an extension of GRA for facilitating group consensus model is proposed and developed to increase the overall satisfaction level of the ultimate decision-making for addressing the increasing complexity problems of the real life. In the following sub-sections, we introduce two MCDM technologies such as GRA and TOPSIS method, and some basic concepts of three-dimension leg-mark selected location method are also introduced.

3.1 GRA

GRA originally proposed and developed by Deng (1982, 1988, 1989a, 1989b) is a multi-factor analysis tool to measure the similarity in order to analyze uncertain relations between the alternative series and the reference series (Deng 1982; Kuo et al. 2008; Lin et al. 2009; Liou et al. 2011). GRA is a basic approach of grey theory, which can process the inaccurate and vague information in grey systems under variable factors and changing environment (Deng 1988; Hsu and Wang 2009). It only requires a reasonable amount of sample data, just a simple and easy calculation and GRA has been widespread applied in addressing kinds of real-world application problems in control, decision-making, data processing as well as systems analysis (Deng 1982, 1989a, b; Hwang and Lin 1987; Kung and Wen 2007; Liu et al. 2011). The specific calculation procedures and steps are illustrated as follows:

The matrix R with m alternatives and n index of multi-criteria decision problem is presented:

$$R = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

1. Standardize the raw matrix R:
   The standardization process is described as follows:

   (a) Benefit criteria: the larger value is better. It can be computed and gotten as follows:

   $$x'_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \tag{2}$$

   (b) Cost criteria: the smaller value is better. It can be computed and gotten as follows:

   $$x'_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \tag{3}$$

   (c) Suitability criteria: the value closer to the objective value x_{ob} is better and it can be computed and gotten as follows:

   $$x'_{ij} = 1 - \frac{\left|x_{ij} - x_{ob}\right|}{\max\left\{\max_i x_{ij} - x_{ob}; x_{ob} - \min_i x_{ij}\right\}} \tag{4}$$

2. Construct the normalized matrix R':

$$R' = \begin{bmatrix} x'_{11} & x'_{12} & \cdots & x'_{1n} \\ x_{21} & x_{22} & \cdots & x'_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x'_{m1} & x'_{m2} & \cdots & x'_{mn} \end{bmatrix} \tag{5}$$

3. Generate the reference series $x'(0)$

$$x'(0) = (x'_{11}(0), x'_{12}(0), \ldots x'_{1j}(0) \ldots, x'_{1n}(0)) \tag{6}$$

   where $x'_{1j}(0)$ is the reference value of the jth factor and it can be obtained by the largest normalization value of each factor.

4. Calculate all difference $\Delta_{ij}(0)$ between all the normalization alternative series and the reference series $x'(0)$:

$$\Delta_{ij}(0) = \left|x'(0) - x'_{ij}\right| \tag{7}$$

$$\Delta = \begin{bmatrix} \Delta_{11}(0) & \Delta_{12}(0) & \cdots & \Delta_{1n}(0) \\ \Delta_{21}(0) & \Delta_{22}(0) & \cdots & \Delta_{2n}(0) \\ \vdots & \vdots & \vdots & \vdots \\ \Delta_{m1}(0) & \Delta_{m2}(0) & \cdots & \Delta_{mn}(0) \end{bmatrix} \tag{8}$$

5. Compute grey relational coefficient value between all the normalization alternative series and the reference series $\gamma_{ij}(0)$:

$$\gamma_{ij}(0) = \frac{\min_i \min_j \Delta_{ij}(0) + \delta \max_i \max_j \Delta_{ij}(0)}{\Delta_{ij}(0) + \delta \max_i \max_j \Delta_{ij}(0)} \tag{9}$$

where δ is a distinguished coefficient, its value is usually configured to 0.5 to provide good stability and moderate distinguishing effects.
6. Get grey relational degree Γ_i:

$$\Gamma_i = \sum_{j=1}^{n} (w(j) \times \gamma_{ij}(0)) \quad \text{where} \quad \sum_{j=1}^{m} w(j) = 1 \tag{10}$$

where w_j is a weight coefficient of ith criteria, and $\sum_{i=1}^{n} w_j = 1$.
7. Rank alternatives.
The greater the grey relational degree Γ_i, the better the chosen alternative.

3.2 TOPSIS

TOPSIS, one well-known typical technology of MCDM technologies, is initially proposed by Hwang and Yoon (1981), in order to evaluate and rank all the evaluation alternatives for addressing complex real-world application problems. TOPSIS is on basis of the principle that the most satisfactory alternative should minimize the distance to the PIS and on the other side maximize the distance to the NIS (Opricovic and Tzeng 2004), that is to say, TOPSIS can find the best chosen alternative by having the nearest distance to the PIS and the farthest distance to the NIS. Finally, all the chosen alternatives are ranked by the relative closeness degree. The detailed procedures of TOPSIS are described and introduced as follows:

1. Determine the normalization matrix A. The standardization value a_{ij} is determined as follows:

$$a_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} (x_{ij})^2}} \quad (1 \le i \le m, \ 1 \le j \le n) \tag{11}$$

2. Computer weighted normalization matrix:

$$D = (a_{ij} * w_j)(1 \le i \le m, 1 \le j \le n) \tag{12}$$

where w_j is a weight coefficient of ith criteria, and $\sum_{i=1}^{n} w_j = 1$.
3. Computer the PIS V^* and determine the NIS V^-:

$$V^* = \{v_1^*, v_2^*, \ldots, v_n^*\} = \left\{ (\max_i v_{ij} \,|j \in J), (\min_i v_{ij} \,\big|j \in J') \right\}$$
$$V^- = \{v_1^-, v_2^-, \ldots, v_n^-\} = \left\{ (\min_i v_{ij} \,|j \in J), (\max_i v_{ij} \,\big|j \in J') \right\} \tag{13}$$

Table 1 Preference ranking of each expert

	1	2	…	i	…	m
DM_1	A_2	A_1		A_i		A_m
DM_2	A_m	A_2		A_1		A_i
DM_3	A_i	A_2		A_m		A_1

4. Obtain the separation measures applying the Euclidean distance formula:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (V_i^j - V^*)^2} \quad (1 \le i \le m,\ 1 \le j \le n)$$
$$S_i^- = \sqrt{\sum_{j=1}^{n} (V_i^j - V^-)^2} \quad (1 \le i \le m,\ 1 \le j \le n) \tag{14}$$

5. Get the relative closeness degree Y_i:

$$Y_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (1 \le i \le m) \tag{15}$$

   where $Y_i \in (0, 1)$, Y_i is closer to 1, the chosen alternative is better.
6. Rank the alternatives.
   The chosen alternatives can be ranked by the relative closeness degree.

3.3 Three-dimension leg-mark selected location method

In this paper, on the basis of the two-dimension leg-mark selected location method, a three-dimension leg-mark selected location method (TDLMSLM) for facilitating group consensus is proposed. Be similar to the two-dimension leg-mark selected location method, TDLMSLM, also on the basis of expert prioritization, is to establish a three-dimensional leg-mark coordinate system for facilitating group consensus in the three members of the group. And it just requires the information of individual preference ranking of each expert. The specific process is presented and given as follows:

Define 1 In the three-dimensional leg-mark coordinate system, the line through the point (1, 1, 1) and the point (2, 2, 2) is defined as the alignment of three-dimensional leg-mark coordinate system, the equation is $e_1 = e_2 = e_3$. Where $e_i (1 \le i \le 3)$ is a unit vector of ith-axis of the three-dimensional leg-mark coordinate system.

Define 2 In the three-dimensional leg-mark coordinate system, the three-dimensional hyperplane $y = e_1 + e_2 + e_3$ is defined as a cross-section of three-dimensional leg-mark coordinate system.

Assume there are $A = \{A_1, A_2, \ldots A_i \ldots A_m\} (1 \le i \le m)$ alternatives and three experts: DM_1, DM_2 and DM_3, the number of the chosen alternatives is m. The preference ranking of each expert are shown as follows, presented in Table 1.

Where $1, 2, \ldots i \ldots m$ represents the number order of each axis. $A_2, A_1, \ldots A_i \ldots A_m$, $A_m, A_2, \ldots A_1 \ldots A_i$ and $A_i, A_2, \ldots A_m \ldots A_1$ given randomly as a example for illustration represents the alternative ranking of each expert. The priorities of experts can be obtained by the ranking of their prestige, experience or social status. Assume DM_1 is prior to DM_2, DM_1 is prior to DM_3, and DM_2 is prior to DM_3. Now, we can establish a three-dimensional leg-mark coordinate system, where X-axis is on behalf of DM_1, Y-axis is on behalf of DM_2, and Z-axis is on behalf of DM_3.

Let $A_{pqr} \in A, (1 \leq p \leq m, 1 \leq q \leq m, 1 \leq r \leq m)$, m is the number of the chosen alternatives. The number of DM_1-axis represents p of A_{pqr}, similarly, the number of DM_2-axis represents q of A_{pqr}, and the number of DM_3-axis represents r of A_{pqr}. Therefore, each A_{pqr} has their unique corresponding position in the leg-mark coordinate system. We can define a function as follows:

$$F_{a_i}(p,q,r) = (p+q+r) + \frac{|p-q|+|p-r|+|q-r|}{10^{\alpha}} + \frac{p}{10^{2\alpha}}(1 \leq i \leq m)$$
$$\alpha = \begin{cases} 1, \ when \ 1 \leq m < 10, \\ 2, \ when \ 10 \leq m < 100, \\ 3, \ when \ 100 \leq m < 1000. \end{cases} \tag{16}$$

According to the value of F, we can get group consensus order of the three experts, the preference rules are as follows:

1. For different F of three alternatives, the smaller the F, the better the chosen alternative;
2. For the same F of three alternatives, the nearer the distance from the alignment, the better the chosen alternative;
3. For the same F and the same distance from the alignment of three alternatives, the smaller the p, the better the chosen alternative.

Given all that, the steps and processes of TDLMSLM can be generalized as follows:

Step 1: Establish the three-dimensional leg-mark coordinate system according to the individual preference ranking of each expert.
Step 2: Find out the corresponding position of the individual preference ranking of each expert in the three-dimensional leg-mark coordinate system and mark it.
Step 3: Compute the F value of each chosen alternative in the three-dimensional leg-mark coordinate system.
Step 4: Determine the group consensus order according to the preference rules.

4 Evaluation method

In this section, an extension of GRA for facilitating group consensus model is proposed and developed to evaluate emergency plan with oil spill. Our proposed model consists of two stages: The stage 1 is to develop an extension of GRA which includes two parts, and the stage 2 is to propose a group consensus facilitation method, based on three-dimension leg-mark selected location method to address the problem of ranking inconsistency in the evaluation of MCDM. The special details are presented as follows:

4.1 Extension of GRA

GRA, firstly proposed and developed by Deng (1982), is devoted to address incomplete, poor and uncertain systems (Zheng et al. 2010). It is a good match for dealing with multi-criteria problems with complex real-world applications between multiple variables and multiple objectives (Tseng 2010). GRA confirms the difference to metric the similarity between the alternative series and the reference series for identifying the most satisfactory chosen alternative (Liou et al. 2011). TOPSIS, well-known as one of MCDM technologies, can be applied to assess the alternative performance by the relative closeness degree. TOPSIS can find the best alternative by the basic principle of minimizing the distance to the PIS and maximizing the distance to the NIS (Chen and Hwang 1992; Opricovic and Tzeng 2004).

So, in this paper, on the basis of the basic concept of a relative closeness degree of TOPSIS, we combine TOPSIS and GRA to obtain the ranking scheme of all the evaluation alternatives by simultaneously computing the grey relational degree to PRS and NRS for increasing the evaluation accuracy. In addition, in this paper, the information of index weights are determined by a mathematical optimization model which also presents the principle that the most satisfactory alternative should have the nearest distance to PRS and the farthest distance to NRS. The implementing processes are detailed as follows:

The matrix R with m alternatives and n criteria of multi-criteria decision problem is presented as follows:

$$R = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{17}$$

7. Construct the normalization matrix R':

$$R' = \begin{bmatrix} x'_{11} & x'_{12} & \cdots & x'_{1n} \\ x_{21} & x_{22} & \cdots & x'_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x'_{m1} & x'_{m2} & \cdots & x'_{mn} \end{bmatrix} \tag{18}$$

8. Generate PRS $x^{+}(0)$ and determine NRS $x^{-}(0)$:

$$x^{+}(0) = (x^{+}_{11}(0), x^{+}_{12}(0), \ldots x^{+}_{1j}(0) \ldots, x^{+}_{1n}(0)) \tag{19}$$

where $x^{+}_{1j}(0)$ is the positive reference value of the jth factor and it can be obtained according to the largest normalization value of each factor.

$$x^{-}(0) = (x^{-}_{11}(0), x^{-}_{12}(0), \ldots x^{-}_{1j}(0) \ldots, x^{-}_{1n}(0)) \tag{20}$$

where $x^{-}_{1j}(0)$ is the negative reference value of the jth factor and it can be obtained according to the smallest normalization value of each factor.

9. Calculate all difference $\Delta^{+}_{ij}(0)$ between all the normalization alternative series and PRS $x^{+}(0)$:

$$\Delta^{+}_{ij}(0) = \left| x^{+}(0) - x'_{ij} \right| \tag{21}$$

$$\Delta^{+} = \begin{bmatrix} \Delta^{+}_{11}(0) & \Delta^{+}_{12}(0) & \cdots & \Delta^{+}_{1n}(0) \\ \Delta^{+}_{21}(0) & \Delta^{+}_{22}(0) & \cdots & \Delta^{+}_{2n}(0) \\ \vdots & \vdots & \vdots & \vdots \\ \Delta^{+}_{m1}(0) & \Delta^{+}_{m2}(0) & \cdots & \Delta^{+}_{mn}(0) \end{bmatrix} \tag{22}$$

Similarly, calculate all difference $\Delta_{ij}^{-}(0)$ between all the normalization alternative series and NRS $x^{-}(0)$:

$$\Delta_{ij}^{-}(0) = \left| x^{-}(0) - x'_{ij} \right| \tag{23}$$

$$\Delta^{-} = \begin{bmatrix} \Delta_{11}^{-}(0) & \Delta_{12}^{-}(0) & \cdots & \Delta_{1n}^{-}(0) \\ \Delta_{21}^{-}(0) & \Delta_{22}^{-}(0) & \cdots & \Delta_{2n}^{-}(0) \\ \vdots & \vdots & \vdots & \vdots \\ \Delta_{m1}^{-}(0) & \Delta_{m2}^{-}(0) & \cdots & \Delta_{mn}^{-}(0) \end{bmatrix} \tag{24}$$

10. Compute grey relational coefficient value between all the normalization alternative series and PRS $\gamma_{ij}^{+}(0)$:

$$\gamma_{ij}^{+}(0) = \frac{\min_i \min_j \Delta_{ij}^{+}(0) + \delta \max_i \max_j \Delta_{ij}^{+}(0)}{\Delta_{ij}^{+}(0) + \delta \max_i \max_j \Delta_{ij}^{+}(0)} \tag{25}$$

Similarly, compute grey relational coefficient value between all the normalization alternative series and NRS $\gamma_{ij}^{-}(0)$:

$$\gamma_{ij}^{-}(0) = \frac{\min_i \min_j \Delta_{ij}^{-}(0) + \delta \max_i \max_j \Delta_{ij}^{-}(0)}{\Delta_{ij}^{-}(0) + \delta \max_i \max_j \Delta_{ij}^{-}(0)} \tag{26}$$

where δ is a distinguished coefficient, its value is usually configured to 0.5 to provide good stability and moderate distinguishing effects.

11. Calculate grey relational degree between all the normalization alternative series and PRS Γ_i^{+}:

$$\Gamma_i^{+} = \sum_{j=1}^{n} w_j \gamma_{ij}^{+} (1 \leq i \leq m) \tag{27}$$

Calculate grey relational degree between all the normalization alternative series and NRS Γ_i^{-}:

$$\Gamma_i^{-} = \sum_{j=1}^{n} w_j \gamma_{ij}^{-} (1 \leq i \leq m) \tag{28}$$

The principle of the extension of GRA is that the most satisfactory alternative should have the nearest distance to PRS and the farthest distance to NRS. However, the information of index weights is incomplete known. The importance of index weights to great extent determines the effectiveness of decision-making process. Therefore, in the article, a multi-objective mathematical optimization model, which can measure the basic principle of the extension of GRA, is developed and used to calculate the information of index weights, the specific process is presented as follows:

$$\begin{cases} \max D_i^{+} = \sum_{j=1}^{n} w_j x^{+}(0) \\ \min D_i^{-} = \sum_{j=1}^{n} w_j x^{-}(0) \\ \quad \textit{subject to}: w \in H \\ \quad 1 \leq i \leq m, 1 \leq j \leq n \end{cases} \tag{29}$$

Each chosen alternative is non-inferior, meanwhile, there exists no single preference alternative which could reach the best performance (Wei 2010). So the above multi-objective mathematical optimization function can be transformed into a single objective mathematical optimization function, presented as follows:

$$\begin{cases} \max D_i = \sum_{i=1}^{m} \sum_{j=1}^{n} w_j (x^+(0) - x^-(0)) \\ \quad subject\ to : w \in H \\ \quad 1 \le i \le m, 1 \le j \le n \end{cases} \tag{30}$$

According to the formula (30), the initial index weights $w' = (w'_1, w'_2, \ldots w'_n)$ can be computed. And the optimal solution of index weights $w = (w_1, w_2, \ldots w_n)$ considering their importance preference of multi-stakeholders $w'' = (w''_1, w''_2, \ldots w''_n)$ (presented in the empirical process), can be acquired as follows:

$$w_i = \sqrt{w'_i * w''_i} / \sum_{i=1}^{n} \sqrt{w'_i * w''_i} \tag{31}$$

Then, the grey relational degree Γ_i^- and Γ_i^+ can be easily got respectively.

12. Get the relative closeness degree Γ_i:

$$\Gamma_i = \frac{\Gamma_i^-}{(\Gamma_i^- + \Gamma_i^+)} (1 \le i \le m) \tag{32}$$

13. Rank the alternatives.
The chosen alternatives can be ranked by the relative closeness degree Γ_i.

4.2 Group consensus facilitating method

TDLMSLM is based on expert prioritization to establish a three-dimensional leg-mark coordinate system for solving group decision problem where the members of the group consist of three experts. It only requires a little information, just individual preference ranking of each expert, characterized by briefness, objective and simple calculation. So in this paper, a group consensus facilitating method based on three-dimension leg-mark selected location method is proposed and developed for group decision, presented in Sect. 4. The aim is to find the best satisfactory alternatives which increase the overall satisfaction level of the ultimate decision-making for a group of cooperative decision makers to solve the difficult and challenging problem of ranking inconsistency in the evaluation of MCDM.

What's more, the steps and processes of n-dimension leg-mark selected location method for facilitating group consensus are further given, which explores and improves the graphical representation of group decision in coordinate system. Some basic definition and principle are given and introduced as follows:

Define 1 In the n-dimensional leg-mark coordinate system, the line through the point $(1, 1, \ldots, 1)$ and the point $(2, 2, \ldots, 2)$ is defined as the alignment of n-dimensional leg-mark coordinate system, the equation is as follows:

$$e_1 = e_2 = \cdots e_i = \cdots = e_n (1 \le i \le n) \tag{33}$$

where e_i is a unit vector of ith-axis of the n-dimensional leg-mark coordinate system.

Define 2 In the n-dimensional leg-mark coordinate system, the n-dimensional hyper-plane $t = e_1 + e_2 + \cdots e_i + \cdots e_n (1 \le i \le n)$ is defined as a cross-section of three-dimensional leg-mark coordinate system.

Let $A_{p_1 \ldots p_i \ldots p_n} \in A$, $(1 \leq i \leq n)$, the number of the chosen alternatives is n. The number of DM$_1$-axis represents p_1 of $A_{p_1 \ldots p_i \ldots p_n}$, similarly, the number of DM$_i$-axis represents p_i of $A_{p_1 \ldots p_i \ldots p_n}$, the number of DM$_n$-axis represents p_n of $A_{p_1 \ldots p_i \ldots p_n}$. Therefore, each $A_{p_1 \ldots p_i \ldots p_n}$ has their unique corresponding position in the leg-mark coordinate system. We can define a function as follows:

$$F_{a_i}(p_1 \ldots p_i \ldots p_n) = \sum_{i=1}^{n} p_i + \frac{\sum_{i \in k} |p_i - p_k|}{10^{\alpha}} + \frac{p_1}{10^{2\alpha}} (1 \leq i \leq n)$$

$$\alpha = \begin{cases} 1, \; when \; 1 \leq n < 10, \\ 2, \; when \; 10 \leq n < 100, \\ 3, \; when \; 100 \leq n < 1000. \end{cases} \tag{34}$$

Given all that, the steps and processes of n-dimension leg-mark selected location method for facilitating group consensus can be generalized as follows:

Step 1: Establish an n-dimensional leg-mark coordinate system according to the individual preference ranking of each expert.
Step 2: Find out the corresponding position of the individual preference ranking of each expert in the n-dimensional leg-mark coordinate system.
Step 3: Computer the F value of each chosen alternative in the n-dimensional leg-mark coordinate system.
Step 4: Determine group consensus order according to the preference rules, presented in Sect. 3.3.

Finally, the evaluation flowchart of our extension of grey relational analysis for facilitating group consensus model has been shown in Fig. 1.

5 Experiment

In this section, an extension of grey relational analysis for facilitating group consensus model is proposed and developed to evaluate emergency plan with oil spill by an OSCAR simulation experiment, in order to improve and increase the overall satisfaction level of the ultimate decision-making in GDM support system and effectively respond to the crisis management problem of oil spill emergency.

5.1 Problem descriptions

A golden standard of emergency management with oil spill is to minimize the loss and damage by making emergency preplan to deal with the emergency situations (Krohling and Campanharo 2011). However, the design and development of the best emergency preplan with oil spill are very hard to be accomplished because it is accompanied by some variable conditions such as types of oil spill, volume of oil spill, location of oil spill, time, weather situation and the dynamic ocean environment (Liu and Wirtz 2007a; Krohling and Campanharo 2011). Besides, the opinions, benefits and interests of the stakeholders, such as fishermen, policy makers and environmentalists (Wirtz et al. 2004) involved in emergency management with oil spill are difficult to be treated and reflected, although some favorable assessment technologies are promoted and developed (Wirtz et al. 2004; Liu and Wirtz 2007a, b; Liao et al. 2012). There is very difficult to reach a consensus since in general, it will get inevitably contradictory and conflict when evaluating the best emergency preplan among

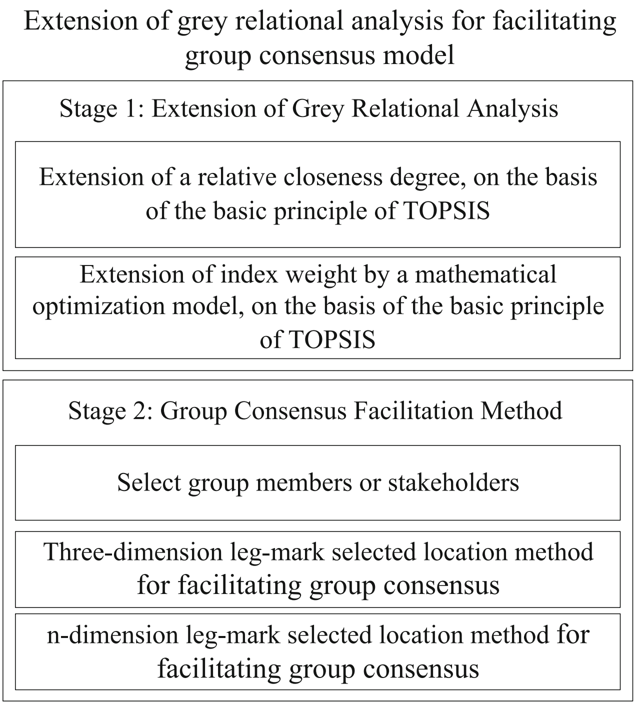

Fig. 1 The evaluation flowchart of our proposed model

multi-stakeholders (Krohling and Campanharo 2011). These motivate our research for new technologies to handle uncertain, imprecise data and variable factors with incommensurate and conflicting criteria, considering reaching a consensus among the stakeholders. So, this paper proposes and develops an extension of GRA for facilitating group consensus model to oil spill emergency management.

5.2 The data and criteria

Like previous research applying fuzzy comprehensive evaluation method by Liu and Wirtz (2007a, b), this paper focuses on the oil spill emergency management of Prestige, which took along 77,000 tons of oil split in the northwest coast of Spain (Liu and Wirtz 2007a). Five chosen emergency alternatives and eight criteria are defined, exampled in detail by Liu and Wirtz (2007a, b). The five chosen emergency alternatives on towing the spilling vessel is direction NE, NW, W, SW and E. And eight criteria is the fishery (F), the tourism (To), the transportation (Tr), the mariculture (M), the residual risk (RR), the reproduction area (RA), the persistence area (PeA) and the protection area (PrA). And the data of each emergency alternative have been simulated by a scenario simulation model called OSCAR, produced by Norwegian: Stiftelsen for industriell og teknisk forskning (SINTEF) (Aamo et al. 1997; Liu 2010). The data have been presented in Table 2 (Liu and Wirtz 2007a, b).

Table 2 The data including five alternatives and eight criteria (2007a, 2007b)

	F	To	Tr	M	RR	RA	PeA	PrA
NE	34.5	27.4	17.8	41.5	55.3	0.3	0.5	30.1
NW	18.5	15.3	5.2	26.6	178.5	0.3	0.6	24.0
W	29.5	24.9	9.2	38.5	168.2	0.4	1.3	31.0
SW	74.7	60.1	3.5	78.0	114.3	4.4	5.9	72.9
E	19.1	15.8	1.4	24.1	20.3	0.7	0.8	18.7

Table 3 The importance preferences of the stakeholders in form of weights

	F	To	Tr	M	RR	RA	PeA	PrA
Freshmen: DM_1	0.225	0.075	0.175	0.275	0.025	0.125	0.075	0.025
Environmentalists: DM_2	0.375	0.075	0.075	0.125	0.125	0.125	0.025	0.075
Policy makers: DM_3	0.125	0.100	0.100	0.100	0.125	0.350	0.050	0.050

Table 4 Normalized decision matrix for freshmen: DM_1

	F	To	Tr	M	RR	RA	PeA	PrA
NE	7.763	2.055	3.115	11.413	1.383	0.038	0.038	0.753
NW	4.163	1.148	0.910	7.315	4.463	0.038	0.045	0.600
W	6.638	1.868	1.610	10.588	4.205	0.050	0.098	0.775
SW	16.808	4.508	0.613	21.450	2.858	0.550	0.443	1.823
E	4.298	1.185	0.245	6.628	0.508	0.088	0.060	0.468

5.3 Empirical process

In the decision making process of emergency plan evaluation with oil spill, there is no doubt that the stakeholders (fishermen: DM_1, environmentalists: DM_2 and policy makers: DM_3) consider that the importance of each criteria are different, because they have different interests, benefits, knowledge, experiences, expertise and the nature of complexity of real-world applications. So in this paper, firstly, the importance preferences of the stakeholders in form of weights are given in Table 3, obtained by subjective weighting method, according as the opinions (such as interests, benefits, knowledge, experiences, expertise) of each stakeholder.

Secondly, on the basis of the importance preferences of the stakeholders presented in Table 3, the normalized decision matrix for each stakeholder can be computed and generated, presented in Tables 4, 5, and 6, respectively.

Then, determine the optimal solution of index weights considering simultaneously both the importance preferences of the stakeholders and the information of index weights on the basis of the basic principle of TOPSIS. The results of the optimal solution of index weights are presented in Table 9, obtained by geometric mean algorithm by integrating the importance preferences of the stakeholders and the information of index weights by the mathematical optimization model.

Now, we introduce how to determine the information of index weights by the mathematical optimization model. Under the oil spill emergency, the information of index weights is partly known, given by opinions of the experts: DM_1, DM_2 and DM_3, it is presented as follows:

Table 5 Normalized decision matrix for environmentalists: DM_2

	F	To	Tr	M	RR	RA	PeA	PrA
NE	12.938	2.055	1.335	5.188	6.913	0.038	0.013	2.258
NW	6.938	1.148	0.390	3.325	22.313	0.038	0.015	1.800
W	11.063	1.868	0.690	4.813	21.025	0.050	0.033	2.325
SW	28.013	4.508	0.263	9.750	14.288	0.550	0.148	5.468
E	7.163	1.185	0.105	3.013	2.538	0.088	0.020	1.403

Table 6 Normalized decision matrix for policy makers: DM_3

	F	To	Tr	M	RR	RA	PeA	PrA
NE	4.313	2.740	1.780	4.150	6.913	0.105	0.025	1.505
NW	2.313	1.530	0.520	2.660	22.313	0.105	0.030	1.200
W	3.688	2.490	0.920	3.850	21.025	0.140	0.065	1.550
SW	9.338	6.010	0.350	7.800	14.288	1.540	0.295	3.645
E	2.388	1.580	0.140	2.410	2.538	0.245	0.040	0.935

Table 7 The Difference between PRS and NRS of the three stakeholders

	F	To	Tr	M	RR	RA	PeA	PrA
DM_1	12.645	3.360	2.870	14.823	3.955	0.513	0.405	1.355
DM_2	21.075	3.360	1.230	6.738	19.775	0.513	0.135	4.065
DM_3	7.025	4.480	1.640	5.390	19.775	1.435	0.270	2.710

Table 8 The initial index weights calculated by the mathematical optimization model

	F	To	Tr	M	RR	RA	PeA	PrA
DM_1	0.15	0.10	0.09	0.08	0.14	0.20	0.13	0.11
DM_2	0.10	0.10	0.09	0.13	0.14	0.20	0.13	0.11
DM_3	0.15	0.10	0.09	0.13	0.09	0.20	0.13	0.11

$$\begin{aligned}H = {} & 0.08 \le w_1 \le 0.15, 0.04 \le w_2 \le 0.10, 0.04 \le w_3 \le 0.09, 0.06 \le w_4 \\ & \le 0.13, 0.05 \le w_5 \le 0.14, 0.11 \le w_6 \le 0.20, 0.06 \le w_7 \le 0.13, 0.05 \le w_8 \\ & \le 0.11, w_1 + w_2 + w_3 + w_4 + w_5 + w_6 + w_7 + w_8 = 1, w_j \ge 0 1 \le j \le 8\end{aligned}$$

The difference between PRS and NRS according to the mathematical optimization model of these three stakeholders is calculated, presented in Table 7.

According to the mathematical optimization model by formula (30), the initial index weights of each stakeholder can be calculated, implemented by Matlab 2012a, the research results are presented and given in Table 8.

The optimal solution of index weights of each stakeholder can be computed by formula (31). The detailed results are presented and given in Table 9.

Table 9 The optimal solution of index weights

	F	To	Tr	M	RR	RA	PeA	PrA
DM_1	0.201	0.095	0.138	0.163	0.065	0.173	0.108	0.057
DM_2	0.209	0.093	0.089	0.137	0.143	0.170	0.061	0.098
DM_3	0.141	0.103	0.098	0.117	0.109	0.272	0.083	0.076

Table 10 The ranking of alternatives of each stakeholder and group consensus

	DM_1	Ranking	DM_2	Ranking	DM_3	Ranking	Consensus
NE	0.599	4	0.615	3	0.630	3	3
NW	0.695	2	0.659	2	0.677	2	2
W	0.621	3	0.595	4	0.619	4	4
SW	0.314	5	0.308	5	0.306	5	5
E	0.738	1	0.739	1	0.734	1	1

Finally, the ranking of all the evaluation alternatives of each stakeholder is calculated according to the extension of GRA by the steps presented in Sect. 4.1. The ranking results of each stakeholder are shown in Table 10.

The ranking of group consensus can be obtained according to the steps and processes of three-dimension leg-mark selected location method, presented in Sect. 3.3. The key and core step is to determine the F value of each alternative, given as follows:

$$F_{NE} = 10.24,\ F_{NW} = 6.02,\ F_W = 11.23,\ F_{SW} = 15.05,\ F_E = 3.01$$

Based on the F value of each alternative, by the preference rules presented by three-dimension leg-mark selected location method in Sect. 3.3, we can obtain the group consensus ranking of alternative NE, NW, W, SW, E is 3, 2, 4, 5, 1 which are also shown in Table 10.

5.4 Result analysis

In Table 10, we can see the best alternative is E, followed by NW, NE and W, the worst alternative is SW. Based on empirical study, we can get a conclusion that our proposed model is not only an extension of GRA to address the oil spill emergency management problems of vague and incomplete information related to related to multi-criteria, complex dynamic environments, but also increases the overall satisfaction level of the ultimate decision-making for a group of cooperative decision makers, which solve the difficult and challenging group decision problem of ranking inconsistency in the evaluation of MCDM involving the benefits and interests of multi-stakeholders.

What's more, for verifying and certifying the effectiveness and feasibility of our model, we further conduct a comparative analysis with two related previous research papers using fuzzy comprehensive evaluation method by Liu and Wirtz (2007a, b). The research results are consistent, they are all that the best alternative is E, followed by NW, NE and W, the worst alternative is SW. That is to say, the rankings of alternative NE, NW, W, SW, E in the three papers are all 3, 2, 4, 5, 1, which demonstrates and verifies the effectiveness and feasibility of our proposed and developed model. Compared with the fuzzy comprehensive evaluation method used previously by Liu and Wirtz (2007a, b), our proposed model gives a consistently result. It ensures that the research results are correct and our proposed model is effective. However, there exists three weaknesses in the fuzzy logic: (1) there is no uniform standard about the normalization of fuzzy membership functions (2) the fuzzy rules is no deed to enumerate all possible configurations of variables (3) there are too many methods for calculate fuzzy logic operations without optimal way to address the corresponding problem (Pan and McMichael 1998). In this paper, grey relational analysis for avoiding weaknesses in the fuzzy logic, is applied to deal with the oil spill emergency management problems of dynamic and variable factors, because GRA, a portion of grey theory (Deng 1982), is a multi-factor analysis tool to analyze uncertain relations between the reference series and alternative series for addressing complex real-world problems marked by vague, incomplete and inaccurate information (Chen and Tzeng 2004).

Emergency decision, such as oil spill emergency management, is an extremely complex multi-criteria optimization problem involving the benefits and interests of multi-stakeholders, multi-criteria and complex dynamic environments (Liu and Wirtz 2007a). And a wise decision should not only reflect the opinion of single decision maker in the complex dynamic environments, but also consider the group preference of the stakeholders such as fishermen, environmentalists and policy makers. Thus, two main integration aspects should be considered in the oil spill emergency decision making process: one is the integration between multi-criteria and the complex dynamic natural environments. The other is the integration among the opinions, benefits and interests of the stakeholders. To realize the two main integration aspects, an extension of grey relational analysis for facilitating group consensus model is proposed and developed to oil spill emergency management involving multi-criteria, complex dynamic environments and the benefits and interests of multi-stakeholders.

6 Discussion and conclusion

Emergency management with oil spill is a very complex decision-making problem, because it is accompanied by vague and incomplete information related to multi-criteria, complex dynamic environments such as types of oil spill, volume of oil spill, rate of oil flowing, location of oil spill, time, weather situation and the dynamic ocean environment (Liu and Wirtz 2007a; Krohling and Campanharo 2011). Besides, the opinions, benefits and interests of the stakeholders, such as fishermen, policy makers and environmentalists (Wirtz et al. 2004) involved in emergency management with oil spill, are difficult to be treated and reflected.

This paper targets efforts to develop a new technology to address the complex emergency decision making problem. So in this article, an extension of GRA for facilitating group consensus model is developed and proposed to oil spill emergency management involving multi-criteria, complex dynamic environments and the benefits and interests of multi-stakeholders, and this paper aims to illustrate, in case of oil spill emergency management, how decision-making process and negotiation process are centralized in a scenario simulation framework. The results demonstrate that our proposed model is feasible and effective by comparative analysis with the previous research papers by Liu and Wirtz (2007a, b). The main research contributions are unfolded and summarized.

Firstly, an extension of GRA is proposed to deal with the oil spill emergency management problems of vague and incomplete information related to multi-criteria, complex dynamic environments. The extension contains two parts: One is to simultaneously compute the grey relational degree to PRS and NRS, on the basis of the basic concept of a relative closeness degree of TOPSIS, for obtaining the ranking of all the chosen alternatives. The other is to determine index weights by a developed mathematical optimization model which also presents the principle that the most satisfactory chosen alternative should have the nearest distance to PRS and the farthest distance to NRS.

Secondly, a group consensus facilitating method, based on three-dimension leg-mark selected location method, is applied to address the difficult and challenging GDM problem of ranking inconsistency in the evaluation of MCDM involving the benefits and interests of multi-stakeholders. What's more, the calculation steps and processes of n-dimension leg-mark selected location method for facilitating group consensus are given and explored in this paper.

In addition, our proposed model can be popularized and explored to deal with other complex real-world problems with multi-alternative, multi-criteria, incomplete information associated to variable factors and different opinions, benefits and interests of multi-stakeholders.

Acknowledgments This research has been partially supported by 2016 Soft Science Research Project of Jiangxi Province, Grants from the National Natural Science Foundation of China (#71433001, #71325001, #91224001, and #71173028).

Compliance with ethical standards

Conflict of interest There are no conflicts of interest to declare.

References

Aamo, O. M., Reed, M., Lewis, A. (1997). Regional contingency planning using the OSCAR oil spill contingency and response model. In *Proceedings of the 20th Arctic and marine oil spill program*. AMOP technical seminar, Canada.

Anaya-Arenas, A. M., Renaud, J., & Ruiz, A. (2014). Relief distribution networks: A systematic review. *Annals of Operations Research*, *223*(1), 53–79.

Belardo, S., Harrald, J., Wallace, W. A., & Ward, J. (1984). A partial covering approach to sitting response resources for major maritime oil spills. *Management Science*, *30*, 1184–1196.

Bragg, J. R., Prince, R. C., Harner, E. J., & Atlas, R. M. (1994). Effectiveness of bioremediation for the Exxon Valdez oil spill. *Nature*, *368*, 413–418.

Chen, S. J., & Hwang, C. L. (1992). *Fuzzy multiple attribute decision making: Methods and applications*. Berlin: Springer.

Chen, M. F., & Tzeng, G. H. (2004). Combining grey relation and TOPSIS concepts for selecting an expatriate host country. *Mathematical and Computer Modelling*, *40*, 1473–1490.

Deng, J. (1982). Control problems of grey systems. *Systems and Control Letters*, *1*, 288–294.

Deng, J. (1988). *Grey system book*. Windsor: Science and Technology Information Services.

Deng, J. (1989a). Introduction to grey theory system. *The Journal of Grey System*, *1*(1), 1–24.

Deng, J. (1989b). Grey information space. *The Journal of Grey System*, *1*(1), 103–117.

Dyer, J. S., Fisburn, P. C., Steuer, R. E., Wallenius, J., & Zionts, S. (1992). Multiple criteria decision making, multi-attribute utility theory: The next ten years. *Management Science*, *38*(5), 645–654.

Goni, G. J., Trinanes, J. A., MacFadyen, A., Streett, D., Olascoaga, M. J., Imhoff, M. L., et al. (2015). *Variability of the deepwater horizon surface oil spill extent and its relationship to varying ocean currents and extreme weather condition*. Berlin: Springer International Publishing.

Hamzaçebi, C., & Pekkaya, M. (2011). Determining of stock investments with grey relational analysis. *Expert Systems with Applications*, *38*(8), 9186–9195.

Helle, I., Ahtiainen, H., Luoma, E., Hänninen, M., & Kuikka, S. (2015). A probabilistic approach for a cost-benefit analysis of oil spill management under uncertainty: A Bayesian network model for the Gulf of Finland. *Journal of Environmental Management*, *158*(1), 122–132.

Hsu, L. C., & Wang, C. H. (2009). Forecasting integrated circuit output using multivariate grey model and grey relational analysis. *Expert Systems with Applications*, *36*(2), 1403–1409.

Huang, S. J., Chiu, N. H., & Chen, L. W. (2008). Integration of the grey relational analysis with genetic algorithm for software effort estimation. *European Journal of Operational Research*, *188*(3), 898–909.

Hwang, C. L., & Lin, M. J. (1987). *Group decision making under multiple criteria: Methods and applications*. Berlin: Springer.

Hwang, C. L., & Yoon, K. (1981). *Multiple attribute decision making methods and applications*. Berlin, Heidelberg: Springer.

Ivanova, M. (2011). Oil spill emergency preparedness in the Russian Arctic: A study of the Murmansk region. *Polar Research*, *30*, 7285–7297.

Keeney, R., & Raiffa, H. (1976). *Decisions with multiple objectives: Preferences and value tradeoffs*. New York: Wiley.

Keramitsoglou, I., Cartalis, C., & Kassomenos, P. (2003). Decision support system for managing oil spill events. *Environmental Management*, *32*(2), 290–298.

Kou, G., & Wu, W. (2014). Multi-criteria decision analysis for emergency medical service assessment. *Annals of Operations Research*. doi:10.1007/s10479-014-1630-6

Kou, G., Ergu, D., & Shang, J. (2014b). Enhancing data consistency in decision matrix: Adapting Hadamard model to mitigate judgment contradiction. *European Journal of Operational Research*, *236*, 261–271. doi:10.1016/J.Ejor.11.035.

Kou, G., & Lin, C. (2014a). A cosine maximization method for the priority vector derivation in AHP. *European Journal of Operational Research*, *235*, 225–232. doi:10.1016/j.ejor.2013.10.019.

Kou, G., Lu, Y., Peng, Y., & Shi, Y. (2012). Evaluation of classification algorithms using MCDM and rank correlation. *International Journal of Information Technology & Decision Making*, *11*(1), 197–225. doi:10.1142/S0219622012500095.

Kou, G., Peng, Y., & Wang, G. (2014). Evaluation of clustering algorithms for financial risk analysis using MCDM methods. *Information Sciences*, *275*, 1–12. doi:10.1016/J.Ins.02.137. (SCI).

Kou, G., Shi, Y., & Wang, S. (2011). Multiple criteria decision making and decision support systems-Guest editor's introduction. *Decision Support Systems*, *51*, 247–249.

Krohling, R. A., & Campanharo, V. C. (2011). Fuzzy TOPSIS for group decision making: A case study for accidents with oil spill in the sea. *Expert Systems with Applications*, *38*, 4190–4197.

Krohling, R., & Rigo, D. (2009). Fuzzy group decision making for management of oil spill responses. *Applications of Soft Computing*, *58*, 3–12.

Kung, C. Y., & Wen, K. L. (2007). Applying grey relational analysis and grey decision-making to evaluate the relationship between company attributes and its financial performance-A case study of venture capital enterprises in Taiwan. *Decision Support Systems*, *44*(3), 842–852.

Kuo, Y., Yang, T., & Huang, G. W. (2008). The use of grey relational analysis in solving multiple attribute decision making problems. *Computers & Industrial Engineering*, *55*(1), 80–93.

Lai, H. H., Lin, Y. C., & Yeh, C. H. (2005). Form design of product image using grey relational analysis and neural network models. *Computers & Operations Research*, *32*, 2689–2711.

Liao, Z. L., Hannam, P. M., Xia, X. W., & Zhao, T. T. (2012). Integration of multi-technology on oil spill emergency preparedness. *Marine Pollution Bulletin*, *64*, 2117–2128.

Lin, Y. H., Lee, P. C., & Chang, T. P. (2009). Practical expert diagnosis model based on the grey relational analysis technique. *Expert Systems with Applications*, *36*(2), 1523–1528.

Liou, J. J. H., Hsu, C. C., Yeh, W. C., & Lin, R. H. (2011). Using a modified grey relation method for improving airline service quality. *Tourism Management*, *32*(6), 1381–1388.

Liu, X. (2010). Integrated modeling of oil spill response strategies: A coastal management case study. *Environmental Science & Policy*, *13*(5), 415–422.

Liu, X., & Wirtz, K. W. (2006). Total oil spill costs and compensations. *Maritime Policy & Management*, *33*(1), 49–60.

Liu, X., & Wirtz, K. W. (2007a). Decision making of oil spill contingency options with fuzzy comprehensive evaluation. *Water Resource Management*, *21*, 663–676.

Liu, X., & Wirtz, K. W. (2007b). Consensus building in oil spill response planning using a fuzzy comprehensive evaluation. *Coastal Management*, *35*, 195–210.

Liu, S. F., Xie, N. M., & Forrest, J. (2011). Novel models of grey relational analysis based on visual angle of similarity and nearness. *Grey Systems: Theory and Application*, *1*(1), 8–18.

MacKenzie, C. A., Baroud, H., & Barker, K. (2014). Static and dynamic resource allocation models for recovery of interdependent systems: Application to the deepwater horizon oil spill. *Annals of Operations Research*, 1–27.

Michel, J., Owens, E. H., Zengel, S., et al. (2013). Extent and degree of shoreline oiling: Deepwater horizon oil spill, Gulf of Mexico, USA. *PLoS One*, *8*(6), e65087.

Opricovic, S., & Tzeng, G. H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research*, *156*(2), 445–455.

Pan, H. P., & McMichael, D. W. (1998). Fuzzy causal probabilistic networks—A new ideal and practical inference engine. In *Proceedings of the first international conference on multisource-multisensor data fusion*, Las Vegas, USA, pp. 101–108.

Park, J., Moore, J. E, I. I., & Richardson, H. W. (2013). The gulf oil spill and economic impacts: extending the national interstate economic model (NIEMO) to account for induced impacts. *Journal of Homeland Security and Emergency Management.*, *10*(1), 231–244.

Passosa, A. C., Teixeirab, M. G., Garciac, K. C., Cardosoc, A. M., & Monteiro, L. F. A. (2014). Gomes. Using the TODIM-FSE method as a decision-making support methodology for oil spill response. *Computers & Operations Research*, *42*, 40–48.

Peng, Y., Kou, G., Wang, G., Wu, W., & Shi, Y. (2011a). Ensemble of software defect predictors: An AHP-based evaluation method. *International Journal of Information Technology & Decision Making*, *10*(1), 187–206.

Peng, Y., & Yu, L. (2014). Multiple criteria decision making in emergency management. *Computers & Operations Research*, *42*, 1–2.

Peng, Y., Zhang, Y., Tang, Y., & Li, S. (2011b). An incident information management framework based on data integration, data mining, and multi-criteria decision making. *Decision Support Systems*, *51*, 316–327.

Psamftis, H. N., Tharakan, G. G., & Ceder, A. (1986). Optimal response to oil spills: The strategic decision case. *Operations Research*, *34*, 203–217.

Psamftis, H. N., & Ziogas, B. O. (1985). A tactical decision algorithm for the optimal dispatching of oil spill cleanup equipment. *Management Science*, *31*, 1475–1491.

Swannell, R. P., Lee, K., & McDonagh, M. (1996). Field evaluations of marine oil spill bioremediation. *Microbiological Reviews*, *60*(2), 342–365.

Tseng, M. L. (2010). Using linguistic preferences and grey relational analysis to evaluate the environmental knowledge management capacity. *Expert Systems with Applications*, *37*(1), 70–81.

Tufekci, S., & Wallace, W. A. (1998). The emerging area of emergency management and engineering. *IEEE Transactions on Engineering Management*, *45*(2), 103–105.

Turskis, Z., & Zavadskas, E. K. (2011). Multiple criteria decision making (MCDM) methods in economics: An overview. *Technological and Economic Development of Economy*, *2*, 397–427.

Vahdani, B., Mousavi, S. M., Tavakkoli-Moghaddam, R., & Hashemi, H. (2013). A new design of the elimination and choice translating reality method for multi-criteria group decision-making in an intuitionistic fuzzy environment. *Applied Mathematical Modeling*, *37*, 1781–1799.

Wallenius, J., Dyer, J. S., Fisburn, P. C., Steuer, R. E., Zionts, S., & Deb, K. (2008). Multiple criteria decision making, multi-attribute utility theory: Recent accomplishments and what lies ahead. *Management Science*, *54*(7), 1336–1349.

Wei, G. W. (2010). GRA method for multiple attribute decision making with incomplete weight information in intuitionistic fuzzy setting. *Knowledge-Based Systems*, *23*, 243–247.

Wirtz, K. W., Adam, S., Liu, X., & Baumburger, N. (2004). Robustness against different implementation of uncertainty in a contingency DSS: The prestige oil spill accident revised. In C. Pahl-Wostl (Hrsg.) *Proceeding of the international environmental modelling and software society conference*, Osnabruek.

Wu, W., Kou, G., & Peng, Y. (2012b). Credit risk evaluation by improved MCDM models. In *BIFE 2012: proceeding of the 5th international conference on business intelligence and financial engineering*, Lanzhou & Tunhuang, China, pp. 191–195

Wu, W., Kou, G., Peng, Y., & Ergu, D. (2012a). Improved AHP-group decision making for investment strategy selection. *Technological and Economic Development of Economy*, *18*(2), 299–316.

Xie, Q. M., Wand, H. B., Wu, D. H., & Zhao, T. (2009). Two dimension leg-mark selected location method of group decision making of slope treatment. *Rock and Soil Mechanics*, *30*(2), 429–432.

Zheng, G., Jing, Y., Huang, H., & Gao, Y. (2010). Application of improved grey relational projection method to evaluate sustainable building envelope performance. *Applied Energy*, *87*, 710–720.