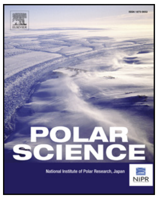
ARTICLE IN PRESS

Polar Science xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Polar Science

journal homepage: www.elsevier.com/locate/polar



Using interpretive structural modeling and fuzzy analytic network process to identify and allocate risks in Arctic shipping strategic alliance

Xiaodan Jiang, Houming Fan*, Ying Zhang, Zhongkai Yuan

Transportation Engineering College, Dalian Maritime University, 1 Linghai Road, Dalian, China

ARTICLE INFO

Keywords:
Arctic
Risk allocation
Strategic alliance
Fuzzy analytic network process (F-ANP)
ISM interpretive structural modeling (ISM)

ABSTRACT

This paper aims to present a novel and useful analytical technique to identify risk factors and calculate risk share proportions in the prospective Arctic shipping strategic alliance, an alliance formed by shipping companies, using the combination of interpretive structural modeling (ISM) and fuzzy analytic network process (F-ANP). Based on in-depth review of relevant literature and interviews with experts, thirty-three risk factors are identified and categorized into five clusters: environment, service and infrastructure, policy, economy, and relation. The ISM technique is applied to identify inherent interactions among risk factors and construct a structural graph. Based on the results of ISM, F-ANP is then used to quantify risk allocation proportion. The results reveal that establishing an alliance can effectively balance the risk sharing proportion among shipping enterprises and the alliance should focus on monitoring the environment, service and communication risks. The proposed modeling approach can be extremely valuable for Arctic shipping alliances to focus on the most prominent risks and effectively allocate risks among partners.

1. Introduction

In the frame of global warming, the Arctic sea ice has been observed to be decreasing in all seasons. The receding Arctic sea ice creates unprecedented opportunities to explore navigable commercial shipping routes in the Arctic waters. The Northeast Sea Route or Northern Sea Route (NSR) along the Russian coast and the Northwest Passage through the Canadian archipelago would substantially reduce the sailing distance between Asia, Europe and North America compared to conventional routes via the Suez/Panama (Wang et al., 2018). Since 1997, shipping companies from many countries have begun their trial navigation on the Arctic routes (NSRA, 2016). Shipping companies from Germany, China, Korea, Denmark, Russia, Norway and Finland have announced their willingness to further invest in the voyage in order to have competitive edges over other competitors (Sun and Zhang, 2017).

Although opening the Arctic routes has created a number of opportunities, the Arctic Ocean still presents major challenges for the maritime industry. Facing hazardous ice conditions, sub-zero temperatures, lack of maritime infrastructures and a sensitive environment, risk management is a crucial topic for those shipping companies that take the initiative of opening a new seaway in the Arctic region. Lee and Kim (2015) identified economic, external and internal barriers and drivers to voyage through NSR from the perspective of shipping companies. Bergström et al. (2016) addressed knowledge, data and regulatory gaps of Arctic sea transport systems. Despite the interest of risk analysis in Arctic shipping, it seems that risk considerations from the viewpoint of strategic alliances are yet to receive adequate attention in the literature.

Strategic alliance is rapidly becoming the preferred way by liner shipping companies to outperform competitors, gain ownership advantage and share risks (Panayides and Wiedmer, 2011). Alliances in shipping industry take various forms according to their agreements. A strategic alliance among shipping companies may aim at co-operating on certain routes in joint investment, employment and utilization of ship, sailing schedules and itineraries, using of terminals, sharing of profits and losses. As such, appropriate risks can be transferred to the shipping company which is supposed to be capable of managing the risks better.

Traditionally, risk is defined as unanticipated or negative variation (Das and Teng, 1998). To control risks, a shipping company might join an Arctic shipping strategic alliance (ASSA). In this paper, the ASSA is a prospective strategic alliance formed by shipping companies that cooperate on Arctic routes in ship employment and utilization, sailing schedules, terminal using and risk sharing. Risk factors that an ASSA is exposed to are different from those faced by a traditional strategic alliance. Moreover, choosing a risk allocation strategy, which can be viewed as the process of identifying alliance risks and determining how

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* Corresponding author.
E-mail address: fhm468@dlmu.edu.cn (H. Fan).

https://doi.org/10.1016/j.polar.2018.05.009
Received 12 March 2018; Received in revised form 24 May 2018; Accepted 25 May 2018

Please cite this article as: Jiang, X., Polar Science (2018), https://doi.org/10.1016/j.polar.2018.05.009

they may be equitably and realistically shared by all the parties in that alliance, is demanding and challenging. The general principle of risk allocation is that risk should be the responsibility of those best able to control and manage them (Nasirzadeh et al., 2014). Risk allocation in a strategic alliance has been found highly variable, subjective and sophisticated. If risks are poorly allocated, extra costs for all parties in the alliance of dealing with disputes might occur and it endangers the stability of the alliance.

This paper aims to address the following problems: If an ASSA is formed, what types of risks are faced and shared by the partners? How to effectively allocate these complex and mingled risks among the partners – that is, how much risk value that the alliance brings with respect to opening a new seaway in the Arctic region is borne by each single shipping line? The paper will examine the risk determinants in an ASSA and reflect the mutual relationships among the risk factors based on Interpretive structural modeling (ISM). On this basis, a theoretical framework is proposed to model risk allocation process in ASSA based on fuzzy analytic network process (F-ANP). An example is used to verify the feasibility of the method. Finally, a brief conclusion is presented.

2. Materials and methods

This paper proposes a method that combines the interpretive structural modeling (ISM) and fuzzy analytic network process (F-ANP) procedures to analyze and allocate the risks in ASSA among shipping companies.

2.1. Interpretive structural modeling

Interpretive structural modeling is the methodology to understand and design the structure of complex issues or systems (Warfield, 1974). It is a powerful qualitative tool for analyzing the interaction among a large number of factors. The contextual relationship among the factors can be determined, in which an overall structure can be extracted from the set of factors. The main steps of ISM are summarized as follows:

1. List all the factors considered for the problem. Define each factor as , $i = 1,2,3, \cdots, n$.
2. Experts are consulted in identifying the relationship among the factors. Establish a structural self-interaction matrix A which shows the pair wise relationship between two factors according to the following rules: (a) If factor directly influences factor e_j, then $a_{ij} = 1$ and $a_{ji} = 0$; (b) If factor e_j directly influences factor , then $a_{ij} = 0$ and $a_{ji} = 1$; (c) If factor and e_j influence each other, then $a_{ij} = 1$ and $a_{ji} = 1$ ($a_{ii} = 1$); (d) If factors and e_j are unrelated, then $a_{ij} = 0$ and $a_{ji} = 0$ (Singhal et al., 2018). The general matrix of A is presented below.

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix}$$

3. Calculate the reachability matrix R from the structural self-interaction matrix A by checking for transitivity. The transitivity of the contextual relationships is an assumption made in ISM which states that if factor is related to factor e_j and factor e_j is related to factor e_k, then factor is necessarily related to factor e_k (Ansari et al., 2013; Hussain et al., 2013).
4. Generate reachability set and antecedent set for each factor according to the reachability matrix. The reachability set contains the factor itself and the factors which it influences, and the antecedent set contains the factor itself and the factors which impact it. The intersection set contains the common factors of reachability set and antecedent set. If the intersection set and the reachability set of a factor are the same, it is put on the top level of a digraph (Singhal et al., 2018).

2.2. Analytic network process

The analytic network process (ANP) is an extension of the hierarchical process which enables the interdependence and feedback among factors (Saaty, 1996). Generally, the ANP system can be divided into two parts: the control level and the network level. The control level includes the goal and the decision criteria. The network level consists of the factors which interact with each other. The ANP steps are as follows:

1. Generate pairwise comparisons to estimate the relative importance of elements at each level.
2. Construct the supermatrix to calculate the priorities of factors. The general form of a supermatrix that was introduced by Saaty (1996) is shown as follow. Supermatrix W is actually a blocked matrix, where each matrix block W_{ij} represents the relationship between the each of the factor in cluster i and the factor in cluster j (Valmohammadi and Dashti, 2016).

$$W = \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1n} \\ W_{21} & W_{22} & \cdots & W_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ W_{n1} & W_{n2} & \cdots & W_{nn} \end{bmatrix}$$

3. Construct the weighted supermatrix to normalize the values of the supermatrix. Calculate the limit matrix to obtain the overall weight of each factor.

2.3. Fuzzy set and fuzzy number

As it is difficult for experts to provide pairwise judgement using exact numerical values, the fuzzy set is used to represent vagueness and imprecision in ANP (Saaty, 1996). A fuzzy set is a set of objects with a continuum of membership grades ranging between zero and one. A triangular fuzzy number (TFN) can be used to represent the relative importance of one factor over another. TFN is denoted by a triplet $\widetilde{N} = (l, m, u)$ where l, m and u are respectively the lower, mean and upper value of a fuzzy scale (Cayir et al., 2017).

The membership function of a TFN is described by Eq. (1):

$$\mu_A(x) = \begin{cases} 0 & x < l \\ (x-l)/(m-l) & l \le x \le m \\ (x-u)/(m-u) & m \le x \le u \\ 0 & x > u \end{cases} \tag{1}$$

Let $\widetilde{A} = (l_1, m_1, u_1)$, $\widetilde{B} = (l_2, m_2, u_2)$ be two TFNs. The multiplication operator can be defined as

$$\widetilde{A} \otimes \widetilde{B} = (l_1 l_2, m_1 m_2, u_1 u_2) \tag{2}$$

2.4. Proposed methodology

The methodology proposed to identify and allocate risks of ASSA is shown in Fig. 1. The ISM procedure is used to identify relevant risk factors and quantify the dependence and feedback relationships among the risk factors. Then the result of ISM is integrated into the network level of ANP. The ANP method is employed to allocate shared risks, since it considers the interrelations and feedbacks of risk factors in a more realistic way. TNF is applied to determine the weights and risk sharing level of each shipping company in the ANP framework using the opinions of experts by allowing them to express their views with linguistic variables. The F-ANP method provides better performance over its classical form due to the fact that the plain ANP method cannot handle the imprecision usually exists in human language and decision-making processes.