Huang, D, Loughney, S and Wang, J

Identification of China's strategic transport passages in the context of the belt and road initiative

Identification of China’s Strategic Transport Passages in the Context of the Belt and Road Initiative

Daozheng Huang[a,b], Sean Loughney[b], Jin Wang[b*]

[a] College of Transport and Communications, Shanghai Maritime University, Shanghai, China

ORCID: https://orcid.org/0000-0002-3799-5342

[b] Liverpool Logistics, Offshore and Marine, Research Institute, Liverpool John Moores University, Liverpool L3 3AF, UK

Abstract

In compliance with the progress of the Belt and Road (B&R) initiative, there exists a notable and continuous increase in the reliance on maritime and onshore transportation. Therefore, unimpeded transportation has become China’s goal to ensure its security of trade and energy resources. This study proposes a useful framework for the quantitative assessment of key Strategic Transport Passages (STPs) to identify and rank China’s STPs in the context of the B&R. An evaluation hierarchy consisting of general criteria and sub-criteria is developed to evaluate the strategic value of alternative passages. The Evidential Reasoning method is employed to carry out the synthesis process with the Intelligent Decision System software package as it is effective when combining both qualitative and quantitative criteria of a complex nature. Finally, China’s top ten STPs and their ranking are determined by their associated strategic values. The Strait of Hormuz ranks first followed by the Strait of Malacca. Alashankou, located in the Xinjiang Uyghur Autonomous Region, China, is the only onshore passage among the top ten STPs. Though the Panama Canal is not involved with the B&R, it is still within the top ten STPs, due to its economic significance.

Keywords: Strategic Transport Passage; Maritime Passage; Strait; Belt and Road Initiative; Evidential Reasoning

* Corresponding author: J.Wang@ljmu.ac.uk, Liverpool Logistics, Offshore and Marine, Research Institute, Liverpool John Moores University, Liverpool L3 3AF, UK

1. Introduction

The Belt and Road (B&R) initiative was adopted by the Chinese government in 2013, to promote worldwide economic development and regional cooperation. The B&R aims to enhance connectivity in policy, infrastructure, trade, finance, and people-to-people ties between associated countries, among which infrastructure connectivity is of priority for developing the initiative (NDRC et al. 2015). The construction of transportation infrastructures such as seaports, dry ports, highways, and railways, both inside and outside China, would benefit the international transportation network significantly (Wang et al. 2016; Li et al. 2020). However, it is a huge challenge to determine the location along the B&R initiative to construct transportation infrastructure, which is capital-intensive. Strategic Transport Passages (STPs) are crucial nodes in the international transportation network, and historically, the hindrance of transport through STPs has caused huge losses to the world economy. Gao and Lu (2019) calculated the increased transportation cost for the Chinese fleet in the event of strait or canal blockage. They found that a blockage of the Strait of Hormuz would have the greatest impact of all straits and canals. Therefore, it is believed that investment in transportation infrastructure around STPs can improve the connectivity and reliability of the transportation network. The identification of China's STPs would support investment decision-making on transportation infrastructure of the B&R initiative. The research of STPs is a multi-disciplinary topic involving geopolitics, international relationships, military activity, and transportation. Different terms are found to represent STP in various literature, such as strategic passage, maritime passage, sea lane, maritime transport notes and strategic shipping pivot. Liang (2011) stated that issues about maritime passages belonged to the high-end politics of a country from a national defense perspective. Former American naval officer Mahan claimed that those who control the ocean, especially strategic narrow channels, control the international trade and wealth. During the Cold war, Stanford (1987) identified America's twelve strategic passages in terms of several principles. In 1986, the United States Navy claimed to control 16 strategic passages around the world, which was extended to 22 passages in 2002.

Maritime passages did not draw much attention from Chinese scholars until 2005 (CIMIR 2005; Li 2005; Liang 2011; Huang, Hu, and Li 2012; Chen 2015; Lv 2015; Li et al. 2019). The earliest Chinese research into maritime passages dates from the sea lane safety research group of the China Institute of Modern International Relations (CIMIR 2005). The research group conducted analyses on the Asia-Pacific Sea lanes, maritime security in Northeast Asia and terrorist activities on the safety of sea lanes. A weakness of this work is that it lacks a comprehensive identification of sea lanes. Li (2005) described the international strategic passages around the world, analyzed their status and functions, emphasized passages associated with China's interest and introduced strategic passage ideas of various countries. To classify China's sea lanes, Du et al. (2014) divided the 21 strategic sea lanes closely related to China's national interests into three levels: sea lanes related to China's core interests, important national interests, and normal national interests. It is necessary to classify the channels according to their national interests and give priority to the protection of channels related to China's core interests. Wang et al. (2018) identified strategic shipping pivots and their spatial patterns at a global scale with a quantitative evaluation model.

In previous literature, the focus has been on the study of maritime passages rather than onshore transport passages, and due to the poor data availability, there is limited quantitative research in literature. Additionally, the implementation of the B&R has had a real impact on the structure of China's international trade and overseas interests, and this impact will become more far-reaching, which in turn will have a corresponding impact on China's STPs. On one hand, the advancement of the B&R may change the pattern of China's STPs, which may result in new STPs, or alter the strategic values of the old ones. Yang et al. (2018) analyzed two new emerging container routes under the B&R initiative and compared them with the Traditional Sea Land-Line using a Fuzzy Multi-Criteria Decision Analysis method. On the other hand, the implementation of the B&R also provides new ideas, tools, and methods for the cooperation mechanism of STPs. For example, the B&R's interconnection of transportation infrastructure provides international public goods and new options for the security cooperation mechanism of STPs. There is some literature that relates to STPs in the context of the B&R (Tang and Jin 2016; Chen 2018; Lee 2018). However, there is no comprehensive and detailed identification of China's STPs with quantitative evaluation models in the context of the B&R. For example, Wang et al. (2018) built a connectivity reliability-cost approach to select paths for China's crude oil transportation. The goal of China's marine strategy has evolved from an initial emphasis on the safe transportation of oil and gas to the protection of the country's comprehensive marine rights and interests (Wang et al., 2018). Therefore, the focus of attention has been expanded from finding solutions for the 'Malacca Paradox', to developing strategies on the layout and regulation of multiple STPs.

This research aims to identify and rank China's STPs in the context of the B&R using real data. Both maritime and onshore transport passages are considered in this research. An evaluation model, utilizing the Evidential Reasoning (ER) method, is built to carry out the identification process. Section 2 defines the concept of STPs and introduces alternatives. The identification methodology is illustrated in Section 3. Section 4 presents a specific case study of identifying China's STPs. Finally, conclusions are drawn in Section 5.

1.1. Evidential Reasoning

The ER approach offers a rational and reproducible methodology to aggregate uncertain, incomplete, and vague data. ER uses the concept of 'degree of belief' to elicit a decision-maker's preference. The degree of belief can be described as the degree of expectation that an alternative will yield an anticipated outcome on a particular criterion. An individual's degree of belief depends on the knowledge of the subject and the experience (Wang et al. 1995; Yang & Xu 2002; Sadeghi et al. 2018). The ER approach has been developed particularly for multiple attribute decision making problems with both qualitative and quantitative criteria under uncertainties utilizes individuals' knowledge, expertise, and experience in the forms of belief functions. The major advantage of ER is its ability to handle incomplete, uncertain, and vague as well as complete and precise data. However, there are two quantitative parts to ER, one is the belief degrees, and the other is the relative weights of the criteria. Analytical Hierarchy Process (AHP) is an ideal solution to develop these weights as the data gathering process can incorporate both the belief degree determination and Pairwise Comparisons (PCs), which is a tremendous advantage in the data gathering process. This is particularly true when utilizing non-probability sampling, as it allows experts to complete the surveys for both ER and AHP at the same time, thus, limiting the level of uncertainty and randomness related to separate surveys for other mixed approaches (Sönmez et al. 2012). Thus, the ER approach, combined with AHP is ideal for application to the assessment of China's STPs.

2. Concept and alternatives

2.1. Definition of strategic transport passage

A dedicated review of the definitions of transport passages in Table 1 shows that there is no uniform or standard definition. However, different STPs around the world have some common characteristics. The highlights of transport passages are summarized as below.

- Almost all the references refer to transport passage as a place, where the terms zone, area, and location are utilized in the literature. Some studies such as Stanford (1987) and Huang, Hu, and Li (2012) limit an STP to be a narrow place while others do not. Straits and canals are regarded as transport passages in all literature reviewed, and some literature also considers ports or seas as maritime passages.
- Connectivity is the fundamental function of a transport passage. Some definitions use the verb "*connect*" or *"transit"* to show the connectivity characteristics of a transport passage. Due to the connectivity, transport passages are natural routes to transport cargo. A large amount of cargo throughput is a key feature of STPs (Huang, Hu, and Li 2012; Wang 2018).
- Two terminologies with the keyword of "*strategic*" state the importance of passages in their definitions (Wang et al. 2018; Stanford 1987). Positively, Wang et al. (2018) stated that strategic shipping pivots played a critical role in the international shipping network. However, a definition from Stanford (1987) mentioned in a negative way that the denied or contested use of strategic passages critically impaired the conduct of national policies.
- All the definitions focus on maritime passages while onshore transport passages are neglected.

This research intends to define STP not only in the maritime sector but also in the onshore sector. Based on the review of the above literature, here, a STP is defined as *a strategic narrow zone where two areas connect and overlap, through which large volumes of vital goods are transported* and will be referred to as a node in this research.

Table 1. Concept of strategic transport passages.

Terminology	Definition	Sub-type	Reference	Organization
Strategic passage	Narrow body of navigable water connecting two stretches of the high seas at which the territorial seas of two land areas meet and overlap, whose denied or contested use critically impairs the conduct of national policies.	Canals, straits	Stanford (1987)	American Naval Ocean Research and Development Activity
Maritime passage	A long narrow zone of water through which a large amount of vital goods transit.	Canals, straits	Huang, Hu, and Li (2012)	Shanghai Jiao Tong University
Strategic shipping pivot	A location which both controls and contains a shipping organization and therefore plays a critical role in the network.	Strategic hubs, channels, and sea areas	Wang et al. (2018)	China Academy of Science
Maritime transport node	A specific maritime area with a special geographical location or special supply function for ships at sea.	Canals, straits, and important ports	Li et al. (2019)	Dalian Maritime University

2.2. Alternative transport passages

21 alternative transport passages are considered in this research including 18 maritime passages and 3 onshore passages. 18 maritime passages are selected because they are important maritime passages studied in previous literature, such as Stanford (1987), Li (2005), Lv (2015), and Wang et al. (2018). Three onshore passages are identified as Alashankou, Erlianhaote and Manzhouli, which are all typical railway terminals on the China Railway Express. Currently, three main corridors, namely west corridor, east corridor, and middle corridor, between China and Europe have taken shape. Alashankou, Erlianhaote and Manzhouli are export railway terminals of the west, middle and east corridors, respectively. The names and regions of all 21 alternative transport passages are listed in Table 2.

Table 2. Alternative transport passages.

Region	Name	Region	Name
Pacific Ocean	Bering Strait	Atlantic Ocean	English Channel
	Korea Strait		Kiel Canal
	Lombok Strait		Strait of Gibraltar
	Makassar Strait	Indian Ocean	Bab el-Mandeb Strait
	Panama Canal		Mozambique Channel
	Soya-kaikyo		Strait of Hormuz
	Strait of Malacca	Mediterranean Sea	Straits of Bosphorus/Dardanelles
	Sunda Strait		Suez Canal
	Taiwan Strait	Onshore	Alashankou
	Tsugaru-kaikyo		Erlianhaote
			Manzhouli

3. Methodology

A step-by-step evaluation methodology is developed to determine the most significant STPs regarding the B&R. The evaluation criteria, the weights of the criteria, the evaluation grades, and belief degrees are four crucial parts of the methodology. Further information regarding the application of the ER algorithm can be found in the following references (Wang et al. 1995; Yang 2001; Yang and Xu 2002; Sadeghi et al. 2018). Figure 1 outlines the methodological framework of this research. To ensure that a coherent method is established, knowledge is obtained through reviewing literature and collecting expert judgement through questionnaires.

Figure 1. Methodological framework for identifying strategic transport passages.

3.1. Identification of initial evaluation criteria

Intensive literature review was carried out to identify the appropriate and relevant criteria to evaluate the strategic values of alternative passages (Chen 2018; Huang et al. 2021; Li 2005; Wang 2018; Stanford 1987). Based on the literature review, the following evaluation criteria are identified for use in this study.

- *Physical situation (X)* indicates the location, physical area, and other natural characteristics of a passage. In this criterion, there are four associated sub-criteria, which are *Vicinity to China (e_1),* *Connectivity (e_2), Traffic capacity (e_3)* and *External condition (e_4)*. *Vicinity to China* is the physical distance of a passage from China. *Connectivity* is the fundamental physical characteristics of a passage as stated in the definition of STP. The indicators to represent *Traffic capacity* are different due to the different characteristics of maritime transportation and onshore rail transportation. In the maritime sector, *Traffic capacity* is indicated by the water depth and width of a passage, while in the onshore sector, *Traffic capacity* is defined by the maximum annual tonnage of cargoes that can pass through the passage. *External condition* represents the environmental condition of a passage, including weather, wave and currents.

- *Economic value (Y)* underpins the economic contribution a passage has made to the global economy. *Volume of cargoes transported (e_5)* is selected as a sub-criterion to indicate the economic value of a passage in terms of the volume of cargoes transported through the passage. In addition to the volume of cargoes transported, the type of cargo is also vital. For example, strategic materials, such as crude oil, are more important than normal cargoes, such as clothes, to the economy of a country. Thus, *Strategic material (e_6)* is added as another sub-criterion. The transportation of oil accounts for about one third of the international trade cargoes in tonnage, making oil far more valuable than other strategic materials such as iron ore, coal, and grain. Thus, the volume of oil transported through a passage is selected to represent the sub-criterion of *Strategic material*.

- *Substitutability (Z)* is an indicator that shows the level of potential replacements of a passage. The more substitutes a passage has, the less important it is. Generally, if a substitute passage is used, there would be an additional distance. Thus, both *The number of substitutes (e_7)* and *Added distance of substitutes (e_8)* are identified as the sub-criteria of *Substitutability*. *Added distance of substitutes* is represented by the minimum added distance to take the substitute passage. The shortest route is employed when there is more than one substitute passage.

- *Involvement with the B&R (T)* is considered as an indicator regarding the relationship with the B&R to evaluate strategic values of alternative passages. Straits like the Panama Canal will receive the lowest score here as they are not part of the B&R initiative.

The evaluation hierarchy is presented in Figure 2 which is based on the criteria previously outlined, all alternatives are analyzed against this set of criteria. This evaluation hierarchy denotes the sequence in which the alternatives are to be assessed.

Figure 2. Evaluation hierarchy for strategic transport passages

3.2. Determining evaluation grades for each criterion

Each criterion is characterized by a set of evaluation grades to maintain consistency throughout the problem-solving process. Five evaluation grades noted by $\{H_1, H_2, H_3, H_4, H_5\}$ are selected in order to accurately determine each passage's strategic value. Table 3 shows the evaluation grades of the general criteria and sub-criteria. For example, H_1, H_2, H_3, H_4 and H_5 stand for *Very poor, Poor, Average, Good* and *Very good* respectively when criterion *Physical situation* is considered.

Table 3. Evaluation grades defined for general criteria and sub-criteria.

Criteria	Evaluation grades				
	H_1	H_2	H_3	H_4	H_5
Physical situation	Very poor	Poor	Average	Good	Very good
Economic value	Very low	Low	Average	High	Very high
Substitutability	Very easy	Easy	Average	Difficult	Very difficult
Involvement with the B&R	Not involved	Marginally involved	Involved	Highly involved	Critically involved
Vicinity to China	Very far	Far	Average	Close	Very close
Connectivity	Very bad	Bad	Average	Good	Very good
Traffic capacity	Very weak	Weak	Average	Strong	Very strong
External condition	Very bad	Bad	Average	Good	Very good
Volume of cargoes transported	Very low	Low	Average	High	Very high
Strategic material	None	Seldom	Average	Some	Many
The number of substitutes	More than three	Triple	Double	Single	None
Added distance of substitutes	Very short	Short	Average	Long	Very long

Objective data and qualitative descriptions are both used to determine the evaluation grades and associated belief degrees. The evaluation grades have been defined in a way that allows for the eliciting of expert knowledge in the domain. The criteria *Vicinity to China, Traffic capacity, Volume of cargoes transported, Strategic material, The number of substitutes* and *Added distance of substitutes* are quantitative. To aggregate the initial data using the ER algorithm, the quantitative criteria must be transformed into assessments with a common set of grades in the form of belief structures. Firstly, a pair of best and worst values for each of the quantitative criteria need to be specified. The best and worst values should be derived in such a way that the values of this criterion for all considered alternatives are in the specific range. Next, the best value is normally regarded to be equivalent to the most preferred grade and the worst corresponds to the least preferred, such as *Very good* and *Very poor*, respectively. The value of *Added distance of substitutes* is positive since the considered passage is normally the nearest path. However, when the considered passage itself is not the best route, *Added distance of substitutes* is negative. For example, when considering substitutes for the Lombok Strait, the Strait of Malacca is considered as a substitute, and not part of the planned route. As a result, *Added distance of substitutes* is negative.

The data sources of the quantitative criteria are illustrated here. The *Vicinity to China* of each alternative is measured one by one from a website providing dynamic positions of vessels based on Automatic Identification System and Electronic Navigational Charts (Chuanxun 2020). The depth and width of maritime passages, and *Volumes of cargoes transported* of the alternatives are collected from the Wikipedia. For example, the depth and width of the Strait of Hormuz, and *Volumes of cargoes transported* of the Strait of Hormuz are collected from its definition on Wikipedia (Strait of Hormuz 2020). *Strategic materials* of the passages are collected from the reference (Wang 2018). *The number of substitutes* for the alternatives is determined on a judgmental basis using geographical common knowledge. *Added distance of substitutes* for the alternatives is also measured one by one as the *Vicinity to China* does. Based on the data collection process of the quantitative criteria, the best and worst values for the six quantitative sub-criteria are shown in Table 4.

Table 4. The best and worst values of quantitative criteria.

Quantitative criteria		Best value	Worst value	Measurement unit
Vicinity to China		0	9828	Nautical mile
Traffic capacity	Depth	2000	11	Meter
	Width	386	0.15	Kilometer
	Rail capacity	80	10	Million tons per year
Volume of cargoes transported		1652	0	Million tons per year
Strategic material		1700	0	10,000 barrels of oil per day
The number of substitutes		0	3	-
Added distance of substitutes		9468	-2500	Nautical mile

For other grades between the best and the worst value, equivalent values also need to be identified according to the characteristics of the criteria and expert judgement (Huang, Hu, and Li 2012; Li 2020; Li 2019; Wang 2018). The equivalent rules for grades of quantitative criteria are illustrated in Table 5.

Table 5. The equivalent rules for grades of quantitative criteria.

Criteria		Evaluation grades	Grading scale
Vicinity to China (Nautical mile)		Very far	>= 7000
		Far	$5000 \le x < 7000$
		Average	$3000 \le x < 5000$
		Close	$1000 \le x < 3000$
		Very close	$0 \le x < 1000$
Traffic capacity	Depth (m)	Very shallow	$0 \le x < 15$
		Shallow	$15 \le x < 25$
		Average	$25 \le x < 35$
		Deep	$35 \le x < 50$
		Very deep	≥ 50
	Width (km)	Very narrow	$0 \le x < 1$
		Narrow	$1 \le x < 50$
		Average	$50 \le x < 100$
		Wide	$100 \le x < 200$
		Very wide	≥ 200
	Rail capacity (Million tons per year)	Very weak	$0 \le x < 100$
		Weak	$100 \le x < 200$
		Average	$200 \le x < 500$
		Strong	$500 \le x < 1000$
		Very strong	≥ 1000
Volume of cargoes transported (Million tons per year)		Very low	$0 \le x < 10$
		Low	$10 \le x < 100$
		Average	$100 \le x < 1000$
		High	$1000 \le x < 2000$
		Very high	≥ 2000
Strategic material (10,000 barrels of oil per day)		None	$0 \le x < 1$
		Seldom	$1 \le x < 10$
		Average	$10 \le x < 100$
		Some	$100 \le x < 1000$
		Many	$1000 \le x < 2000$
The number of substitutes		None	0
		Single	1
		Double	2
		Triple	3
		More than three	> 3
Added distance of substitutes		Very short	≤ -2500
		Short	$-2500 < x \le 0$
		Average	$0 < x \le 2500$
		Long	$2500 < x \le 5000$
		Very long	> 5000

Other three criteria (*i.e. Connectivity*, *External condition* and *Involvement with the B&R*) are expressed in terms of a qualitative assessment. The explanations of the grades for the three qualitative criteria are illustrated in Table 6.

Table 6. The explanations of evaluation grades defined for qualitative criteria.

Criteria	Evaluation grades	Explanations
Connectivity	Very poor	Do not connect areas
	Poor	Do not connect important areas
	Average	Connect regional areas
	Good	Connect global areas, such as seas
	Very good	Connect strategic areas, usually oceans
External condition	Very bad	Very bad weather, very strong currents, typhoon, or very shallow water
	Bad	Bad weather, currents, shallow water
	Average	Normal weather, slight current or wind, normal water depth
	Good	Good weather, no currents or wind, deep water
	Very good	Very good weather, no currents or wind, very deep water
Involvement with the B&R	Not involved	Far away from the B&R and has no relationship with the B&R
	Marginally involved	Near the B&R
	Involved	Located along the Silk Road Economic Belt or the 21^{st} Century Maritime Silk Road
	Highly involved	Component of the Silk Road Economic Belt or the 21^{st} Century Maritime Silk Road
	Critically involved	Critical component of the Silk Road Economic Belt or the 21^{st} Century Maritime Silk Road

3.3. Weights of criteria based on Analytical Hierarchy Process

The relative weights of the criteria are a key part of the assessment and ranking process of alternative STPs.

AHP is a classic and widely used methodology to obtain the relative weights of criteria. In this research, PCs are utilized through qualitative assessment from expert judgement with questionnaires, which are then applied to the AHP methodology to determine the weights of criteria.

A questionnaire is designed to collect expert opinions towards the importance of each criterion, and in this research the questionnaire consists of four parts. The first part is the basic information of experts to outline their expertise and knowledge level in the field. The second and third parts relate to the PCs of the general criteria and sub-criteria, respectively. The fourth part designed to collect the belief structure of each alternative to criterion *Involvement with the B&R.*

3.4. Assessment of criteria based on quantitative data and expert opinion.

Suppose there are *N* sub-criteria e_i $(i=1, 2, ..., N)$ associated with the general criteria *X*. The set of sub-criteria is defined by Equation 1.

$$E = \{e_1, e_2, ..., e_i, ..., e_N\}. \tag{1}$$

Suppose the weights of sub-criteria are given by Equation 2.

$$\omega = \{\omega_1, \omega_2, ..., \omega_i, ..., \omega_N\} \tag{2}$$

where ω_i is the weight of the i^{th} sub-criterion (e_i) with $0 \le \omega_i \le 1$ (Yang & Xu 2002; Li & Liao 2007).

Suppose there are *L* evaluation grades defined collectively to provide a full set of standards for the assessment of an attribute, as shown by Equation 3:

$$H = \{H_1, H_2, ..., H_l, ..., H_L\} \tag{3}$$

where H_l $(l=1,2,...,L)$ is the l^{th} evaluation grade and it is assumed that H_{l+1} is preferred to H_l. Given the assessment for $e_i (i = 1, 2, ..., N)$ an alternative can be represented by Equation 4:

$$S(e_i) = \{(H_{l,i}, \beta_{l,i}), l = 1, ..., L\}\ i = 1, ..., N \tag{4}$$

where $\beta_{l,i}$ is the belief degree that the sub-criterion e_i is assessed to the grade $H_{l,i}$ ($\beta_{l,i} \ge 0, \sum_{l=1}^{L} \beta_{l,i} = 1$, $i = 1, ...,$ N). The assessment of an attribute, $S(e_i)$ is complete if the sum of the belief degrees is equal to 1, *i.e.,* $\sum_{l=1}^{L} \beta_{l,i} = 1$.

A belief function in terms of the evaluation grades and associated belief degrees is formulated in order to obtain the belief degrees associated with the evaluation grades for each alternative.

Suppose h_i^{η} is the quantitative value of the η^{th} ($\eta=1,2,...,21$) STP for the i^{th} criterion. Suppose h_i^{η} lies between $H_{l,i}$ and $H_{l+1,i}$. Then, the belief structure of the STP for the criterion can be calculated by Equations 5-7.

$$S^{\eta}(e_i) = \{(H_{l,i}, \beta_{l,i}); (H_{l+1,i}, \beta_{l+1,i})\} \tag{5}$$

$$\beta_{l,i} = (H_{l+1,i} - h_i^{\eta})/(H_{l+1,i} - H_{l,i}) \tag{6}$$

$$\beta_{l+1,i} = 1 - \beta_{l,i}. \tag{7}$$

Belief structures of the alternatives for qualitative criteria *Connectivity* and *External condition* are drawn from their relevant characteristics. The belief structures of the alternatives for *Involvement with the B&R* are determined by expert judgement through questionnaire surveys. The survey is outlined in Section 4.2.

The problem now is to aggregate the assessments for all of the associated sub-criteria. This is where the ER algorithm is applied. Let β_l (l=1, 2, ..., L) be the belief degree of a general criterion of an alternative, where β_l is generated by aggregating the assessment for all the sub-criteria associated with the general criterion.

3.5. Evidential Reasoning algorithm

Once the weights and belief structures of the sub-criteria are determined, the ER algorithm can be applied to aggregate the sub-criteria to determine the belief structures for the general criteria. Similarly, once the belief structures for the general criteria are determined, they can be aggregated to find the overall *Strategic value* for each alternative STP.

Let $m_{l,i}$ be the probability mass representing the degree to which the i^{th} sub-criterion, e_i, supports the hypothesis that the general criteria X is assessed to the l^{th} grade, H_l. Similarly, let $m_{H,i}$ be the remaining probability mass unassigned to any individual evaluation grade after all grades have been considered for the assessment of the general attribute. In terms of the sub-criterion e_i, the probability mass is calculated by Equation 8:

$$m_{l,i} = \omega_i \beta_{l,i} \; l = 1, ..., L. \tag{8}$$

Similarly, $m_{H,i}$ is given by Equation 9:

$$m_{H,i} = 1 - \sum_{l=1}^{L} m_{l,i} = 1 - \omega_i \sum_{l=1}^{L} \beta_{l,i}. \tag{9}$$

Define $E_{I(i)}$ as the subset of the i sub-criteria, as given by Equation 10:

$$E_{I(i)} = \{e_1, e_2, ..., e_i\}. \tag{10}$$

Let $m_{l,I(i)}$ be the probability mass defined as the degree to which all *i* criteria in $E_{I(i)}$ support the hypothesis that the general criterion *X* is assessed to the grade H_l. Similarly, $m_{H,I(i)}$ is the remaining probability mass which is unassigned to individual grades after all of the sub-criteria in $E_{I(i)}$ have been assessed. The terms $m_{l,I(i)}$ and $m_{H,I(i)}$ can be determined by combining the basic probability masses $m_{l,j}$ and $m_{H,j}$ for all values of *l=1,...,L; j=1,...i.*

Given the definitions and terms outlined in the above paragraphs the ER algorithm can be demonstrated by Equations 11, 12 and 13:

$$m_{l,I(i+1)} = K_{I(i+1)}(m_{l,I(i)}m_{l,i+1} + m_{l,I(i)}m_{H,i+1} + m_{H,I(i)}m_{l,i+1}) \quad l = i,\ldots,L \tag{11}$$

$$m_{H,I(i+1)} = K_{I(i+1)}m_{H,I(i)}m_{H,i+1} \tag{12}$$

$$K_{I(i+1)} = [1 - \sum_{t=1}^{L}\sum_{\substack{j=1 \\ j\neq t}}^{L} m_{t,I(i)}m_{j,i+1}]^{-1} \quad i = 1,\ldots,N-1 \tag{13}$$

where $K_{I(i+1)}$ is a normalizing factor so that $\sum_{l=1}^{L} m_{l,I(i+1)} + m_{H,I(i+1)} = 1$. It is important to note that $m_{l,I(1)} = m_{l,1}$ for l=1,...,L and $m_{H,I(1)} = m_{H,1}$. The results in $m_{l,I(N)}$ and $m_{H,I(N)}$ are not dependent on the order that the sub-criteria are aggregated. In other words, the criteria can be aggregated in any order and the results will remain the same.

Furthermore, in the ER algorithm, the combined belief degree β_l must be found in order to finalize the decision-making process. This is calculated by applying Equation 14.

$$\beta_l = m_{l,I(N)}/(1 - m_{H,I(N)}), l = 1,\ldots,L. \tag{14}$$

3.6. Analysis of the results, utility assessment and ranking

Suppose the utility of an evaluation grade, H_l, is denoted by $u(H_l)$. The utility of the evaluation grade must be determined beforehand, with $u(H_1) = 0$ and $u(H_5) = 1$ assuming there are five evaluation grades (Yang 2001). If there is a lack of information, then the values of $u(H_l)$ can be assumed to be equidistant, as shown by Equation 15:

$$u(H_l) \in \{u(H_1) = 0, u(H_2) = 0.25, u(H_3) = 0.5, u(H_4) = 0.75, u(H_5) = 1\}. \tag{15}$$

The estimated utility for the general criteria *X* is calculated by Equation 16.

$$u(X) = \sum_{l=1}^{L} u(H_l)\beta_l. \tag{16}$$

In Equation 16 the term β_l determines the likelihood that *X* is assessed to a grade H_l. When the belief degrees of the general criteria have been obtained, the belief degrees of the Strategic value can be obtained in the same aggregation process. Finally, the *Strategic Value* of the alternatives can be ranked according to the descending order of their utility values.

4. Identification of China's strategic transport passages

4.1. Determining the weights of each criterion and consistency check

Five complete questionnaires were gathered from domain experts. Five experts' judgments have been utilized and proven to be consistent given the consistency check within the AHP algorithm. The five experts' expertise and experience are outlined as follows:

- All 5 experts are currently in the employment of the international transportation industry and knowledgeable with the research topic.
- All experts have a postgraduate qualification and have 5 or more years' experience within the transportation industry.

Sample sizes in this type of research can be small to support the depth of case-oriented analysis that is fundamental to this mode of inquiry. Competent domain experts were employed to provide suitable information in the samples. Furthermore, non-probability sampling is useful in small scale research where specific knowledge is required. This is the case in this study where specific knowledge of China's STPs is essential to the research (Cohen et al. 2018; Vasileiou et al. 2018).

The PC and AHP methodologies and calculations are not demonstrated here. However, the Consistency Ratios (CR) of the PC and AHP analyses have been obtained to provide some verification to the data collected. The CR value for the general criteria was calculated as 0.006. This means that the degree of consistency within the PC is acceptable as the CR value is much less than 0.10 (Saaty 1990; Saaty 1994). Similarly, calculations are conducted for the other sub-criteria in the PC, with the CR calculated as 0.0327 for *Physical situation* (e_1, e_2, e_3 and e_4). It is also acceptable for *Physical situation* as its CR is much less than 0.10. For the remaining three criteria, it is not possible to check the CRs because there are only two sub-criteria for *Economic value* and *Substitutability,* and no sub-criteria for *Involvement with the B&R*. CR calculations are not possible for matrices of 2×2 or less as Saaty's Random Index value for a 2×2 matrix is zero. Utilizing the PC and AHP methods, the weights for all the general criteria and sub-criteria are calculated and are demonstrated in Table 7.

Table 7. Calculated weights for the general and sub-criteria for use in the analysis.

General criteria	Weights	Sub-criteria	Notation	Weights
Physical situation (*X*)	16.60%	*Vicinity to China*	e_1	21.07%
		Connectivity	e_2	27.93%
		Traffic capacity	e_3	28.38%
		External condition	e_4	22.62%
			SUM	100.00%
Economic value (*Y*)	55.95%	*Volume of cargoes transported*	e_5	37.27%
		Strategic material	e_6	62.73%
			SUM	100.00%
Substitutability (*Z*)	15.84%	*The number of substitutes*	e_7	65.03%
		Added distance of substitutes	e_8	34.97%
			SUM	100.00%
Involvement with the B&R (*T*)	11.61%		e_9	100.00%
SUM	100.00%	SUM		100.00%

4.2. Determine the belief structure of each alternative to each evaluation grade.

The belief degrees associated with five evaluation grades are obtained through the application of navigation charts, literature review, questionnaires, and databases. The belief degrees for the criteria *Involvement with the B&R* are determined from the questionnaire responses. The percentage of experts who tick the box of a certain evaluation grade (from 1 to 5) determines the belief degree associated with this grade for a given alternative. The belief degrees associated with the evaluation grades of each alternative, under criterion *Involvement with the B&R,* are shown in Table 8.

Table 8. Belief degrees of each alternative to criterion *Involvement with the B&R.*

Alternatives	Grades				
	Not involved	Marginally involved	Involved	Highly involved	Critically involved
Strait of Malacca	0	0	0	0.2	0.8
Makassar Strait	0.04	0.04	0.44	0.44	0.04
Lombok Strait	0.04	0.24	0.24	0.44	0.04
Sunda Strait	0	0.2	0	0.8	0
Taiwan Strait	0	0.2	0	0.6	0.2
Korea Strait	0.2	0.6	0	0.2	0
Soya-kaikyo	0.44	0.24	0.04	0.24	0.04
Tsugaru-kaikyo	0.44	0.24	0.24	0.04	0.04
Bering Strait	0.6	0.2	0.2	0	0
English Channel	0.2	0.4	0.4	0	0
Strait of Gibraltar	0.04	0.44	0.04	0.44	0.04
Kiel Canal	0.28	0.28	0.28	0.08	0.08
Strait of Hormuz	0.08	0.08	0.08	0.48	0.28
Bab el-Mandeb Strait	0.08	0.08	0.08	0.48	0.28
Mozambique Channel	0.24	0.04	0.24	0.44	0.04
Suez Canal	0	0	0	0.4	0.6
Straits of Bosphorus/Dardanelles	0.08	0.28	0.48	0.08	0.08
Alashankou	0	0	0.4	0.4	0.2
Manzhouli	0	0	0.6	0.4	0
Erlianhaote	0	0.2	0.6	0.2	0
Panama Canal	0.4	0.2	0.2	0	0.2

The synthesized belief degrees associated with the evaluation grades for 6 of the 21 alternative passages for *Physical situation* are demonstrated in Table 9. The belief structures associated with the evaluation grades for all the alternative passages are given in Appendix 1.

Table 9. The completed belief degrees of *Physical situation* for 6 of the 21 alternative passages.

Criteria	Sub-criteria		Passages						Evaluation grade
			Strait of Malacca	Taiwan Strait	Strait of Hormuz	Suez Canal	Panama Canal	Alashankou	
Physical situation	Vicinity to China (e_1)		0	0	0.3045	1	1	0	Very far
			0	0	0.6955	0	0	0	Far
			0.1235	0	0	0	0	0	Average
			0.8765	0.08	0	0	0	0	Close
			0	0.92	0	0	0	1	Very close
	Connectivity(e_2)		0	0	0	0	0	0	Very bad
			0	0	0	0	0	0	Bad
			0	0.6	0	0	0	0.6	Average
			0.3	0.4	0.4	0.4	0.3	0.4	Good
			0.7	0	0.6	0.6	0.7	0	Very good
	Traffic capacity (e_3)	Depth	0	0	0	0	0.1334	-	Very shallow
			0	0	0	0.25	0.8666	-	Shallow
			1	0	0	0.75	0	-	Average
			0	0	0	0	0	-	Deep
			0	1	1	0	0	-	Very deep
		Width	0	0	0	0.72	0.85	-	Very narrow
			0.2653	0	0	0.28	0.15	-	Narrow
			0.7347	0	0.72	0	0	-	Average
			0	0.7	0.2	0	0	-	Wide
			0	0.3	0	0	0	-	Very wide
		Rail capacity	-	-	-	-	-	0.6	Very weak
			-	-	-	-	-	0.4	Weak
			-	-	-	-	-	0	Average
			-	-	-	-	-	0	Strong
			-	-	-	-	-	0	Very strong
	External condition (e_4)		0	0	0	0	0	0	Very bad
			0	0	0.6	0.2	0.2	0	Bad
			0.2	0.2	0.4	0.6	0.6	0	Average
			0.6	0.6	0	0.2	0.2	0.6	Good
			0.2	0.2	0	0	0	0.4	Very good

4.3. Aggregation assessment based on Evidential Reasoning.

The problem now is how the belief degrees can be aggregated to arrive at an assessment as to identify the STPs. To demonstrate the procedure of the ER algorithm, the detailed steps of the calculation are shown for generating the assessment for criterion *Physical situation* (X), by aggregating two sub-criteria, *Vicinity to China* (e_1) and *Connectivity* (e_2), for the Strait of Malacca. The evaluation grades have been defined in

Equation 3 and Table 9, thus, the following belief degrees associated with the evaluation grades can be stated:

$$\beta_{1,1}=0,\ \ \beta_{2,1}=0,\ \ \beta_{3,1}=0.1235,\ \ \beta_{4,1}=0.8765,\ \ \beta_{5,1}=0$$

$$\beta_{1,2}=0,\ \ \beta_{2,2}=0,\ \ \beta_{3,2}=0,\ \ \beta_{4,2}=0.3,\ \ \beta_{5,2}=0.7$$

As the weights have been calculated, the basic probability masses can be calculated by utilizing Equations 5 and 6.

$$m_{1,1}=0,\ \ m_{2,1}=0,\ \ m_{3,1}=0.0260\ ,\ \ m_{4,1}=0.1847\ ,\ \ m_{5,1}=0\ ,\ \ \sum_{l=1}^{L} m_{l,1}=0.2107\ \ \therefore\ \ m_{H,1}=0.7893$$

$$m_{1,2}=0,\ \ m_{2,2}=0\ ,\ \ m_{3,2}=0,\ \ m_{4,2}=0.0838\ ,\ \ m_{5,2}=0.1955\ \ ,\ \ \sum_{l=1}^{L} m_{l,2}=0.2793\ \ \therefore\ \ m_{H,2}=0.7207$$

It is now possible to use Equations 11, 12 and 13 to calculate the combined probability masses and the normalizing factor, *K*.

$$\sum_{\substack{t=1\\ j\neq t}}^{5} m_{t,I(1)}m_{j,2}=(m_{1,1}m_{2,2}+m_{1,1}m_{3,2}+m_{1,1}m_{4,2}+m_{1,1}m_{5,2})=0+0+0+0=0$$

$$\sum_{\substack{t=2\\ j\neq t}}^{5} m_{t,I(1)}m_{j,2}=(m_{2,1}m_{1,2}+m_{2,1}m_{3,2}+m_{2,1}m_{4,2}+m_{2,1}m_{5,2})=0+0+0+0=0$$

$$\sum_{\substack{t=3\\ j\neq t}}^{5} m_{t,I(1)}m_{j,2}=(m_{3,1}m_{1,2}+m_{3,1}m_{2,2}+m_{3,1}m_{4,2}+m_{3,1}m_{5,2})=0+0+0.0022+0.0051=0.0073$$

$$\sum_{\substack{t=4\\ j\neq t}}^{5} m_{t,I(1)}m_{j,2}=(m_{4,1}m_{1,2}+m_{4,1}m_{2,2}+m_{4,1}m_{3,2}+m_{4,1}m_{5,2})=0+0+0+0.0361=0.0361$$

$$\sum_{\substack{t=5\\ j\neq t}}^{5} m_{t,I(1)}m_{j,2}=(m_{5,1}m_{1,2}+m_{5,1}m_{2,2}+m_{5,1}m_{3,2}+m_{5,1}m_{4,2})=0+0+0+0=0$$

$$K_{I(2)}=[1-(0.0073+0.0361)]^{-1}=1.0453$$

Given that the value of $K_{I(2)}$ has been determined, Equations 11 and 12 can be utilized, along with the basic probability masses.

$$m_{1,I(2)}=K_{I(2)}(m_{1,1}m_{1,2}+m_{1,1}m_{H,2}+m_{H,1}m_{1,2})=0$$

$$m_{2,I(2)}=K_{I(2)}(m_{2,1}m_{2,2}+m_{2,1}m_{H,2}+m_{H,1}m_{2,2})=0$$

$$m_{3,I(2)}=K_{I(2)}(m_{3,1}m_{3,2}+m_{3,1}m_{H,2}+m_{H,1}m_{3,2})=0.0196$$

$$m_{4,I(2)}=K_{I(2)}(m_{4,1}m_{4,2}+m_{4,1}m_{H,2}+m_{H,1}m_{4,2})=0.2244$$

$$m_{5,I(2)}=K_{I(2)}(m_{5,1}m_{5,2}+m_{5,1}m_{H,2}+m_{H,1}m_{5,2})=0.1613$$

$$m_{H,I(2)}=K_{I(2)}m_{H,1}m_{H,2}=0.5946$$

The two sub-criteria, *Vicinity to China* and *Connectivity* have been aggregated, and it is possible to determine the combined belief degrees for this aggregation. These belief degrees are calculated using Equation 14.

$$\beta_1 = m_{1,I(2)} / (1 - m_{H,I(2)}) = 0/(1-0.5946) = 0$$

$$\beta_2 = m_{2,I(2)} / (1 - m_{H,I(2)}) = 0/(1-0.5946) = 0$$

$$\beta_3 = m_{3,I(2)} / (1 - m_{H,I(2)}) = 0.0196/(1-0.5946) = 0.0484$$

$$\beta_4 = m_{4,I(2)} / (1 - m_{H,I(2)}) = 0.2244/(1-0.5946) = 0.5537$$

$$\beta_5 = m_{5,I(2)} / (1 - m_{H,I(2)}) = 0.1613/(1-0.5946) = 0.3980$$

$$\sum_{l=1}^{5} \beta_l = 1, \quad \therefore \ \beta_H = 0$$

where β_H is the residual belief that is calculated in the event that $\sum_{l=1}^{L} \beta_l \neq 1$.

The outlined calculation process represents the aggregation of two sub-criteria. Given the sub-criteria under the general criterion *Physical situation,* the results obtained above can be used to combine with the third sub-criterion, and then with the fourth. Following the complete aggregation of the sub-criteria e_1, e_2, e_3 and $e_4,$ the overall assessment of the general criterion *Physical situation,* for the Strait of Malacca can be obtained.

$$\begin{aligned} &S(Physical\ situation) = S(e_1 \otimes e_2 \otimes e_3 \otimes e_4) \\ &= \{(Very\ bad, 0); (Bad, 0.0169); (Average, 0.2464); (Good, 0.4355); (Very\ good, 0.3012)\}. \end{aligned}$$

It should be noted that it does not change the results if the criteria are aggregated in a different order. This calculation process is applied to all 21 alternative passages, for all the general criteria and sub-criteria. The complex calculations are achieved through the application of the Intelligent Decision System software as it is an ER software package and clearly displays the results.

4.4. Ranking of strategic transport passages

Each passage can be ranked based on their aggregated belief degrees, and this is accomplished through utility assessment. Equations 15 and 16 are applied and the rank of each passage, in terms of *Strategic Value*, can be determined. The utility value of each evaluation grade, $u(H_l)$, is assumed to be equidistant from 0 to 1, as shown in Equation 15.

By applying the aggregated belief data calculated in the previous section and Equations 16, the overall utility ranking of the Strait of Malacca, in terms of *Physical situation (X)*, can be determined.

$$\begin{aligned} &u(X) = u(H_1)\beta_1 + u(H_2)\beta_2 + u(H_3)\beta_3 + u(H_4)\beta_4 + u(H_5)\beta_5 \\ &= 0 \times 0 + 0.25 \times 0.0169 + 0.5 \times 0.2464 + 0.75 \times 0.4355 + 1 \times 0.3012 = 0.7552. \end{aligned}$$

This utility assessment is conducted for every alternative under the general criteria and the overall strategic value. Table 10 demonstrates the utility assessment results for the general criterion *Physical situation*. The Taiwan Strait ranks first in terms of the *Physical situation*. The Taiwan Strait, the Korea Strait, the Strait of Malacca and the Bering Strait make up the top four passages and are all located near to the western coast of China in the Pacific Ocean.

Table 10. Utility assessment for criterion *Physical situation.*

PHYSICAL SITUATION		
Rank	Value	Passage
1	0.7600	Taiwan Strait
2	0.7554	Korea Strait
3	0.7552	Strait of Malacca
4	0.7533	Bering Strait
5	0.5778	Strait of Hormuz
6	0.5710	Makassar Strait
7	0.5556	Bab el-Mandeb Strait
8	0.5497	Strait of Gibraltar
9	0.5459	Alashankou
10	0.5425	Soya-kaikyo
11	0.5395	Manzhouli
12	0.5395	Mozambique Channel
13	0.5367	Tsugaru-kaikyo
14	0.5286	Suez Canal
15	0.5218	Kiel Canal
16	0.5204	Lombok Strait
17	0.5191	Erlianhaote
18	0.5188	Sunda Strait
19	0.4847	English Channel
20	0.4787	Panama Canal
21	0.4434	Straits of Bosphorus/Dardanelles

Table 11 shows the results of the utility assessment for the general criterion *Economic value.* The Strait of Malacca ranks first because a large volume of cargo passes through it annually, including many strategic materials, such as crude oil. However, it can be seen from Table 12 that the Strait of Malacca ranks 15th in terms of *Substitutability*. For criterion *Substitutability*, five passages with no viable substitutes rank first.

Table 11. Utility assessment for criterion *Economic value.*

ECONOMIC VALUE		
Rank	Value	Passage
1	0.8787	Strait of Malacca
2	0.8048	Strait of Hormuz
3	0.5883	Panama Canal
4	0.4898	Bab el-Mandeb Strait
5	0.4759	Suez Canal
6	0.3540	Taiwan Strait
6	0.3540	Korea Strait
6	0.3540	English Channel
9	0.3525	Strait of Gibraltar
10	0.2794	Kiel Canal
11	0.2702	Alashankou
12	0.1997	Straits of Bosphorus/Dardanelles
13	0.1762	Lombok Strait
14	0.1599	Makassar Strait
15	0.1518	Soya-kaikyo
15	0.1518	Tsugaru-kaikyo
17	0.1274	Sunda Strait
18	0.0949	Mozambique Channel
19	0.0340	Manzhouli
20	0.0049	Erlianhaote
21	0.0000	Bering Strait

Table 12. Utility assessment for criterion *Substitutability.*

SUBSTITUTABILITY		
Rank	Value	Passage
1	1.0000	Strait of Hormuz
1	1.0000	Straits of Bosphorus/Dardanelles
1	1.0000	Alashankou
1	1.0000	Manzhouli
1	1.0000	Erlianhaote
6	0.5931	Panama Canal
7	0.5257	Strait of Gibraltar
7	0.5257	Bab el-Mandeb Strait
7	0.5257	Suez Canal
10	0.5004	Bering Strait
11	0.4733	English Channel
12	0.4635	Kiel Canal
13	0.4551	Mozambique Channel
14	0.4081	Taiwan Strait
15	0.0931	Strait of Malacca
16	0.0719	Korea Strait
17	0.0519	Soya-kaikyo
17	0.0519	Tsugaru-kaikyo
19	0.0000	Makassar Strait
19	0.0000	Lombok Strait
19	0.0000	Sunda Strait

As for *Involvement with the B&R,* the Strait of Malacca ranks first as shown in Table 13, followed by the Suez Canal, both of which are critical nodes along the 21st Century Maritime Silk Road. Furthermore, the Panama Canal and Bearing Straits rank last as they are not involved with the B&R.

Table 13. Utility assessment for criterion *Involvement with the B&R.*

INVOLVEMENT WITH THE B&R		
Rank	Value	Passage
1	0.9500	Strait of Malacca
2	0.9000	Suez Canal
3	0.7000	Taiwan Strait
3	0.7000	Strait of Hormuz
3	0.7000	Bab el-Mandeb Strait
3	0.7000	Alashankou
7	0.6500	Sunda Strait
8	0.6000	Makassar Strait
9	0.6000	Manzhouli
10	0.5500	Lombok Strait
11	0.5000	Erlianhaote
11	0.5000	Mozambique Channel
11	0.5000	Strait of Gibraltar
14	0.4500	Straits of Bosphorus/Dardanelles
15	0.3500	Kiel Canal
16	0.3000	Korea Strait
16	0.3000	Soya-kaikyo
16	0.3000	English Channel
19	0.2500	Tsugaru-kaikyo
20	0.1500	Bering Strait
20	0.1500	Panama Canal

The overall utility assessment for the *Strategic value* of the 21 alternatives is shown in Table 14. Strategically, the Strait of Hormuz is assessed as the most important because it is the only entrance/exit to the Persian Gulf thus providing invaluable access to strategic materials such as crude oil. Historically, it has been a classical threat to block the Strait of Hormuz, and if it were blocked during times of conflict, the economic loss around the globe would be hugely significant. In some literature, the Strait of Malacca was regarded as the most important passage (Wang 2018). In our research, the Strait of Malacca ranks first in terms of *Economic value* but second in terms of the overall strategic value. The reason is that in this research *Substitutability* is considered as a significant general criterion and there are two potential substitutes for the Strait of Malacca. For the decision-makers of China, possible risks associated with the blockage of the Strait of Hormuz need more attention. The Suez Canal and the Bab el-Mandeb Strait, which are two key passages along the 21st century maritime silk road, rank the third and fourth, respectively. Even though the economic importance of the Panama Canal ranks the third as shown in Table 11, the overall utility of the canal is the fifth due to its low involvement with the B&R.

As for the onshore passages, Alashankou (onshore) is the only one that ranks within the top ten passages as a viable route in the Silk Road Economic Belt. Onshore passages are regarded as substitute options when maritime passages are blocked. The route from Alashankou to the Europe, such as the China-Europe Railway Express, deserves more attention and investment for the resilience of China's whole transportation network.

Table 14. Overall utility assessment for *Strategic value.*

STRATEGIC VALUE		
Rank	Value	Passage
1	0.8024	Strait of Hormuz
2	0.7571	Strait of Malacca
3	0.5399	Suez Canal
4	0.5281	Bab el-Mandeb Strait
5	0.5221	Panama Canal
6	0.4867	Alashankou
7	0.4798	Taiwan Strait
8	0.4356	Strait of Gibraltar
9	0.3953	Straits of Bosphorus/Dardanelles
10	0.3849	English Channel
11	0.3569	Kiel Canal
12	0.3540	Korea Strait
13	0.3430	Manzhouli
14	0.3087	Erlianhaote
15	0.2755	Mozambique Channel
16	0.2442	Makassar Strait
17	0.2399	Lombok Strait
18	0.2220	Bering Strait
19	0.2214	Sunda Strait
20	0.2062	Soya-kaikyo
21	0.2012	Tsugaru-kaikyo

To illustrate the importance of the STPs together with their geographic positions, the geographic distribution of the top ten STPs is shown in Figure 3 and their strategic values are represented by the size of the respective symbolic circles. It can be found that all the top ten passages are located in the Eurasia continent within the B&R except for the Panama Canal. The Panama Canal is not involved with the initiative; however, the weight of criterion *Involvement with the B&R* is approximately only 10%, thus it does not carry as much influence in the aggregation as other criteria. In addition, the Panama Canal is so economically important that it is still within the top ten passages in the context of the B&R.

Figure 3. Geographic distribution of China's top ten strategic transport passages.

4.5. Discussion and implications

This research contributes to the identification of China's STPs in the context of the Belt and Road initiative. The research implications of this study are draw from both theoretical and practical perspectives as follows.

In terms of the theoretical implications, a generic framework has been developed to identify China's STPs in the context of the B&R initiative. The ER approach, which is widely used in risk assessment and decision-making applications, is introduced to assess the strategic importance of both maritime and onshore transport passages along the B&R initiative. The ER method provides decision-makers with a comprehensive evaluation of the strategic value of transport passages.

The results of this research contribute to the implementation of the B&R initiative. Firstly, the ranking result can provide decision-makers with an insight into the different strategic levels of STPs. It also provides a guide for rationalizing the investment resources. Secondly, even though the B&R initiative is made up of one maritime road and one onshore road, maritime passages along the 21st century maritime silk road account for many STPs. The research indicates that more attention should be paid to investment in transportation infrastructures such as ports. Finally, this research has developed an assessment hierarchy through a careful investigation and hence the policy makers can use the hierarchy as a strategic dashboard for assessment, monitoring, and improvement.

5. Conclusion

This research identifies China's Strategic Transport Passages (STPs) in the context of the B&R initiative using the Evidential Reasoning methodology, based upon an evaluation hierarchy consisting of general criteria and sub-criteria. The identification of STPs is vital, not only to assess the strategic values of the passages but also to provide a reference for the optimal decision-making for the development of transport infrastructure of the B&R. This is essential for key issues such as China's resource allocation in securing and maintaining its global transportation reliability.

Nine maritime passages and one onshore passage are identified as China's top ten STPs. They are the Strait of Hormuz, the Strait of Malacca, the Suez Canal, the Bab el-Mandeb Strait, the Panama Canal, Alashankou, the Taiwan Strait, the Strait of Gibraltar, the Straits of Bosphorus/Dardanelles, and the English Channel in order of their strategic values. Strategically, in the maritime sector, the Strait of Hormuz ranks first followed by the Strait of Malacca. Alashankou, located in the Xinjiang Uyghur Autonomous Region, China, is the only onshore passage within the top ten strategic passages. This is understandable as it is a crucial passage along the Silk Road Economic Belt connecting China and Europe. The Panama Canal is the only top ten strategic transport passage which is not involved with the B&R but is ranked highly due to its economic significance.

One weakness of this research is that geopolitical factor is not considered. The geopolitical factor is an important one that affects the safety level of the transport passages. If a passage is surrounded by many countries, it is possible that there are instabilities between surrounding countries. However, it is extremely difficult, if not impossible, to quantify the geopolitical factor, thus this research has only considered the geographic position, *Vicinity to China*. If the geopolitical factor is considered, Taiwan strait would become more important because it is involved in the core interests of China.

Future research may focus on two aspects; i) to identify the strategic values of passages in a dynamic mode, and ii) the safety assessment of China's STPs to figure out their associated safety levels.

Acknowledgements

The authors would like to thank the experts who have provided their subjective judgements through the questionnaire. This research is partially supported by [the National Key Research and Development Program of China #1] under Grant [No. 2019FYB1600602] and [Ministry of Education in China #2] under Grant [No. 19YJCGJW003].

References

1. Chen, F. 2015. "Research on Shipping Channel Security Cooperation Mechanism of Southeast Asia Area." *Journal of Chongqing Jiao Tong University (Social Sciences Edition)* 15 (1): 19-23.
2. Chen, X. 2018. "Comparative Research of Multiple Transportation Corridors for Sino-EU Trade in the Background of the Belt and Road Initiative." *Logistics Engineering and Management* 40 (8): 7-11.
3. Chuanxun, http://www.shipxy.com/Ship/Index, accessed May 1st, 2020.
4. CIMIR (China Institute of Modern International Relations). 2005. Sea Lane Security and International Cooperation. Current Affairs Press.
5. Cohen, L., L. Manion, and K. Morrison. 2018. Chapter 12 Sampling. In: Research Methods in Education. New York: Routledge 8th Edition. 202 - 227.
6. Du, J., H. Qiu, and H. Hu. 2014. "The Safety of Sea Lane: An Analysis and Thinking Based on National Benefit Relativity." *Journal of Nanchang University* 45 (03): 62-67.
7. Gao, T. H., and J. Lu. 2019. "The Impacts of Strait and Canal Blockages on the Transportation Costs of the Chinese Fleet in the Shipping Network." *Maritime Policy & Management* 46 (6): 669-686. doi: 10.1080/03088839.2019.1594423.
8. Huang, D.Z., Y.M. Hua, S. Loughney, E. Blanco-Davis, and J. Wang. 2021. Lifespan cost analysis of alternatives to global sulphur emission limit with uncertainties. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment* 235(4), 921-930. doi: 10.1177/1475090220983140.
9. Huang, D.Z., H. Hu, and Y. Z. Li. 2012. "Application of Fuzzy Logic to Safety Risk Assessment of China's Maritime Passages." *Transportation Research Record: Journal of the Transportation Research*

Board, 2273: 112-120. doi: 10.3141/2273-14.

10. Lee, P. T. W., Z. H. Hu, S. J. Lee, K. S. Choi, and S. H. Shin, 2018. "Research Trends and Agenda on the Belt and Road (B&R) Initiative with a Focus on Maritime Transport." *Maritime Policy &Management* 45 (3): 282-300. doi: 10.1080/03088839.2017.1400189.
11. Li, K. X., K. C. Lin, M. Jin, K. F. Yuen, Z. L. Yang, and Y. Xiao. 2020. "Impact of the belt and road initiative on commercial maritime power." *Transportation Research Part A: Policy and Practice,135*. doi: 10.1016/j.tra.2020.02.023.
12. Liang, F. 2011. "On Maritime Strategic Access." Beijing, Current Affairs Press.
13. Li, B. 2005. "Research on International Strategic Passages." Beijing: Party School of the Central Committee of Communist Party of China.
14. Li, B., J. Li, and J. Lu, 2019. "Research on the Coupled Risk of Key Nodes in Maritime Transport Based on Improved Catastrophe Theory." *Sustainability* 11(17): 4640. doi: 10.3390/su11174640.
15. Li, Y., and X. Liao, 2007. "Decision Support for Risk Analysis on Dynamic Alliance." *Decision Support Systems.* 42: 2043-2059. doi: 10.1016/j.dss.2004.11.008.
16. Lv, J., and S. Wang. 2015. "Safety Evaluation of China's Maritime Transport Key Nodes." *Journal of Transportation Systems Engineering Information Technology* 15 (1): 30-36.
17. NDRC (National Development and Reform Commission), Ministry of Foreign Affairs and Ministry of Commerce of the People's Republic of China with State Council. 2015. Vision and Actions on Jointly Building Silk Road Economic Belt and 21st-Century Maritime Silk Road, Beijing.
18. Saaty, T. 1990. "How to Make a Decision: The Analytical Hierarchy Process." *Journal of Operational Research* 48: 9-26. doi: 10.1016/0377-2217(90)90057-I.
19. Saaty, T. 1994. Fundamentals of Decision Making. Pittsburgh, PA: RWS Publication.
20. Sadeghi, A., H. Farhad, A. Moghaddam, and M. Qazizadeh. 2018. "Identification of Accident-prone Sections in Roadways with Incomplete and Uncertain Inspection-based Information: A Distributed Hazard Index based on Evidential Reasoning Approach." *Reliability Engineering & System Safety* 178: 278-289. doi: 10.1016/j.ress.2018.06.020.
21. Sönmez, M., J. Yang, G. Graham, and G. Holt. 2012. "An Evidential Reasoning based Decision Making Process for Pre-qualifying Construction Contractors." *Journal of Decision Systems* 11(3-4): 355-381.
22. Stanford, G. 1987. Strategic Passages (No. NORDA-SP-005: 115: 88). Naval Ocean Research and Development Activity NSTL Station MS.
23. Strait of Hormuz, https://simple.wikipedia.org/wiki/Strait_of_Hormuz, accessed May 1st, 2020.
24. Tang, M., and X. Jin. 2016. "Research on the Construction of International Logistics Passages in the Context of Belt & Road Initiative." *Inner Mongolia Science Technology & Economy* 7: 3-5.
25. Vasileiou, K., J. Barnett, S. Thorpe, and T. Young. 2018. "Characterising and justifying sample size sufficiency in interview-based studies: systematic analysis of qualitative health research over a 15-year period." MC Med Res Methodol, 18(148).
26. Wang, C., P. Chen, and Y. Chen. 2018. "The Identification of Global Strategic Shipping Pivots and their

Spatial Patterns." *Journal of Geographical Sciences* 28 (9): 1215-1232.
27. Wang, J., J. Yang, and P. Sen. 1995. "Safety Analysis and Synthesis Using Fuzzy Sets and Evidential Reasoning." *Reliability Engineering & System Safety* 47 (2): 103-118. doi: 10.1016/0951-8320(94)00053-Q.
28. Wang, K., Y. Yuan, X. P. Yan, and M. Zou. 2016. "Hotspots and Challenges of Shipping Development Based on the World Shipping Summit 2015." *Journal of Transport Information and Safety* 34 (1): 10-18.
29. Wang, S., D. Yang, and J. Lu. 2018. "A connectivity reliability-cost approach for path selection in the maritime transportation of China's crude oil imports." *Maritime Policy & Management* 45 (5): 567-584.
30. Yang, D., L.P. Jiang, and A.K.Y. Ng. 2018. "One Belt one Road, but several routes: A case study of new emerging trade corridors connecting the Far East to Europe." *Transportation Research Part A: Policy and Practice* 117: 190-204. https://doi.org/10.1016/j.tra.2018.08.001.
31. Yang, J. 2001. "Rule and Utility based Evidential Reasoning Approach for Multi-attribute Decision Analysis under Uncertainties." *European Journal of Operational Research* 131: 31-61. doi: 10.1016/S0377-2217(99)00441-5.
32. Yang, J., and D. Xu. 2002. "On the Evidential Reasoning Algorithm for Multiple Attribute Decision analysis Under Uncertainty." *IEEE Transactions on Systems, Man and Cybernetics - Part A: Systems and Humans* 32 (3): 289-304. doi: 10.1109/TSMCA.2002.802746.

Appendix 1 The belief structures associated with the evaluation grades for all the alternative passages

		Physical situation						Economic value		Substitutibility		
				Traffic capacity								
NO.	Candidates	Vicinity to China	Connectivity	Depth	Width	Rail capacity	External condition	Volume of cargoes transported	Strategic material	The number of substitutes	Added distance of substitutability	Involvement with the B&R
1	Strait of Malacca	(0.8765,Average;0.1235,Close)	(0.3,Good;0.7,Very good)	(1,Average)	(0.2653,Narrow;0.7347,Average)	-	(0.2,Average;0.6,Good;0.2,Very good)	(0.3480,High;0.6520,Very high)	(0.48,Some;0.52,Many)	(1,Double)	(1,Average)	(0.2,Highly involved; 0.8,Critically involved)
2	Makassar Strait	(0.6315,Average;0.3685,Close)	(0.4,Average;0.6,Good)	(1,Very deep)	(0.8,Deep;0.2,Very deep)	-	(0.6,Bad;0.4,Average)	(0.1934, Low;0.8064,Average)	(1,None)	(1,Double)	(1,Very short)	(0.04,Not involved;0.04,Marginally involved;0.44,Highly involved;0.04,Critically involved)
3	Lombok Strait	(0.798, Avarage; 0.202, Close)	(0.4,Average;0.6,Good)	(1,Very deep)	(0.3061,Narrow;0.6939,Average)	-	(0.6,Good;0.4,Very good)	(0.0098,Low;0.9802,Average)	(1,None)	(1,Double)	(1,Very short)	(0.04,Not invovled;0.24,Mariginally involved;0.24,Involved;0.44,Highly involved;0.04,Critically involved)
4	Sunda Strait	(0.7495,Average;0.2505,Close)	(0.4,Average;0.6,Good)	(1,Very deep)	(0.4898,Narrow;0.5102,Average)	-	(0.6,Bad;0.4,Average)	(0.9276, Average;0.0724,High)	(1,None)	(1,Double)	(0.1192, Very short;0.8808,Short)	(0.2,Marginally involved;0.8,Highly involved)
5	Taiwan Strait	(0.92, Very close; 0.08, Close	(0.6,Average;0.4,Good;	(1,Very deep)	(0.7,Wide;0.3, Very wide)	-	(0.2, Average; 0.6,Good;0.2,Very good)	(1,Very high)	(1,None)	(1,Single)	(0.9744,Short;0.0256, Average)	(0.2, Not involved; 0.6,Highly involved;0.2,Critically involved)
6	Korea Strait	(0.573, Very close; 0.427, Close)	(0.6,Average;0.4,Good)	(1,Very deep)	(0.2,Deep;0.8, Very deep)	-	(0.2,Average;0.6,Good;0.2,Very good)	(1,Very high)	(1,None)	(1,Double)	(0.454,Short;0.546, Average)	(0.2, Not involved; 0.6,Marginally involved; 0.2,Highly involved)
7	Soya-kaikyo	(0.173,Avarage;0.827,Close)	(0.6,Average;0.4,Good)	(1,Very deep)	(0.1429,Narrow;0.8571,Average)	-	(0.6,Bad;0.4,Average)	(0.2851,Low;0.7149,Average)	(1,None)	(1,Double)	(0.8852,Short;0.1148,Average)	(0.44, Not involved; 0.24,Marginally involved;0.04,Involved; 0.24,Highly involved;0.04,Critically involved)
8	Tsugaru-kaikyo	(0.0625,Average;0.9375,Close)	(0.6,Average;0.4,Good)	(1,Very deep)	(0.6429,Narrow;0.3571,Average)	-	(0.6,Bad;0.4,Average)	(0.2851,Low;0.7149,Average)	(1,None)	(1,Double)	(0.8852, Short;0.1148,Average)	(0.44, Not involved; 0.24,Marginally involved;0.24,Involved 0.04,Highly involved;0.04,Critically involved)
9	Bering Strait	(0.2095, Far;0.7905,Average)	(0.3,Good;0.7, Very good)	(0.5,Average;0.5,Deep)	(0.3,Average;0.7, Deep)	-	(0.2,Average;0.6,Good;0.2,Very good)	(1,Very low)	(1,None)	(1,Single)	(0.9884,Average;0.0116,Long)	(0.6, Not involved; 0.2,Marginally involved;0.2,Involved)
10	English Channel	(1,Very far)	(0.4,Average;0.6,Good)	(1,Very deep)	(0.08,Average;0.92,Deep)	-	(0.6,Bad;0.4,Average)	(1,Very high)	(1,None)	(1,Single)	(0.652,Short;0.348, Average)	(0.2, Not involved; 0.4,Marginally involved;0.4,Involved)
11	Strait of Gibraltar	(1,Very far)	(0.3,Good;0.7, Very good)	(1,Very deep)	(0.7755,Narrow;0.2245,Average)	-	(0.6,Bad;0.4,Average)	(0.0177,High;0.9823,Very high)	(1,None)	(1,Single)	(0.3684,Average;0.6316,Long)	(0.04, Not involved; 0.44,Marginally involved;0.04,Involved; 0.44,Highly involved;0.04,Critically involved)
12	Kiel Canal	(1,Very far)	(0.4,Average;0.6,Good)	(0.2667 Very shallow;0.7333, Shallow)	(0.84, Very narrow;0.16,Narrow)	-	(0.2, Average; 0.6,Good;0.2,Very good)	(0.8436,High;0.1564,Very high)	(1,None)	(1,Single)	(0.8356,Short;0.1644,Average)	(0.28, Not involved; 0.28,Marginally involved;0.28,Involved; 0.08,Highly involved;0.08,Critically involved)
13	Strait of Hormuz	(0.3045,Very far; 0.6955, Far)	(0.4,Good;0.6, Very good)	(1,Very deep)	(0.72,Average;0.28,Wide)	-	(0.6,Bad;0.4,Average)	(0.3769,Average;0.6231,High)	(0.3,Some; 0.7,Many)	(1,None)	(1, Very long)	(0.2, Not involved; 0.6,Marginally involved;,Involved 0.6,Highly involved;0.2,Critically involved)
14	Bab el Mandeb	(0.4765,Very far;0.5235, Far)	(0.3,Good;0.7, Very good)	(1,Very deep)	(0.4898,Narrow;0.5102,Average)	-	(0.7,Bad;0.3,Average)	(0.7440,Average;0.2560,High)	(0.6889,Seldom;0.3111,Some)	(1,Single)	(0.3684,Average;0.6316,Long)	(0.08, Not involved; 0.08,Marginally involved;0.08,Involved; 0.48,Highly involved;0.28,Critically involved)
15	Mozambique Channel	(0.9115,Very far;0.0885, Far)	(0.6,Average;0.4,Good)	(1,Very deep)	(1,Very deep)	-	(0.2,Bad;0.6 Average;0.2,Good)	(0.9276,Low;0.0724,Average)	(1,None)	(1,Single)	(0.974,Short;0.026, Average)	(0.24, Not involved; 0.04,Marginally involved;0.24,Involved; 0.44,Highly involved;0.04,Critically involved)
16	Suez Canal	(1,Very far)	(0.4,Good;0.6 Very good)	(0.25,Shallow; 0.75, Average)	(0.72,Very Narrow;0.28,Narrow)	-	(0.2,Bad;0.6 Average;0.2,Good)	(0.7440,Average;0.2560,High)	(0.7556,Seldom;0.2444,Some)	(1,Single)	(0.3684,Average;0.6316,Long)	(0.4,Highly involved;0.6,Critically involved)
17	Strait of Bosphorus/Dardanelles	(1,Very far)	(0.6,Average;0.4,Good)	(0.75,Average; 0.25,Deep)	(0.75,Very Narrow;0.25, Narrow)	-	(0.2,Bad; 0.6 Average;0.2,Good)	(0.7440,Average;0.2560,High)	(1,None)	(1,None)	(1, Very long)	(0.08, Not involved; 0.28,Marginally involved;0.48,Involved; 0.08,Highly involved;0.08,Critically involved)
18	Alashankou	(1,Very close)	(0.6,Average;0.4,Good)	-	-	(0.6,Very low;0.4, Low)	(0.6,Good;0.4,Very good)	(0.8,Very low;0.2,Low)	(0.8223,Seldom;0.1777,Some)	(1,None)	(1, Very long)	(0.4,Involved 0.4,Highly involved;0.2,Critically involved)
19	Manzhouli	(1,Very close)	(0.8,Average;0.	-	-	(0.2, Very low;0.8,	(0.6,Good;0.4,Very	(0.52,Very	(1,None)	(1,None)	(1, Very long)	(0.6,Involved; 0.4,Highly involved)

			2,Good)			Low)	good)	Low;0.48,Low)				
20	Erlianhaote	(1,Very close)	(0.8,Average;0.2,Good)	-	-	(0.9, Very low;0.1, Low)	(0.6,Good;0.4,Very good)	(0.92,Very low;0.08,Low)	(1,None)	(1,None)	(1, Very long)	(0.2,Marginally involved;0.6,Involved 0.2,Highly involved)
21	Panama Canal	(1,Very far)	(0.3,Good;0.7; Very good)	(0.1334 Very shallow;0.8666, Shallow)	(0.85,Very narrow; 0.15, Narrow)	-	(0.2,Bad; 0.6 Average;0.2,Good)	(0.8358,Average;0.1642,High)	(0.1367,Seldom;0.8633,Some)	(1,Single)	(1, Very long)	(0.4, Not involved; 0.2,Marginally involved;0.2,Involved;0.2,Critically involved)

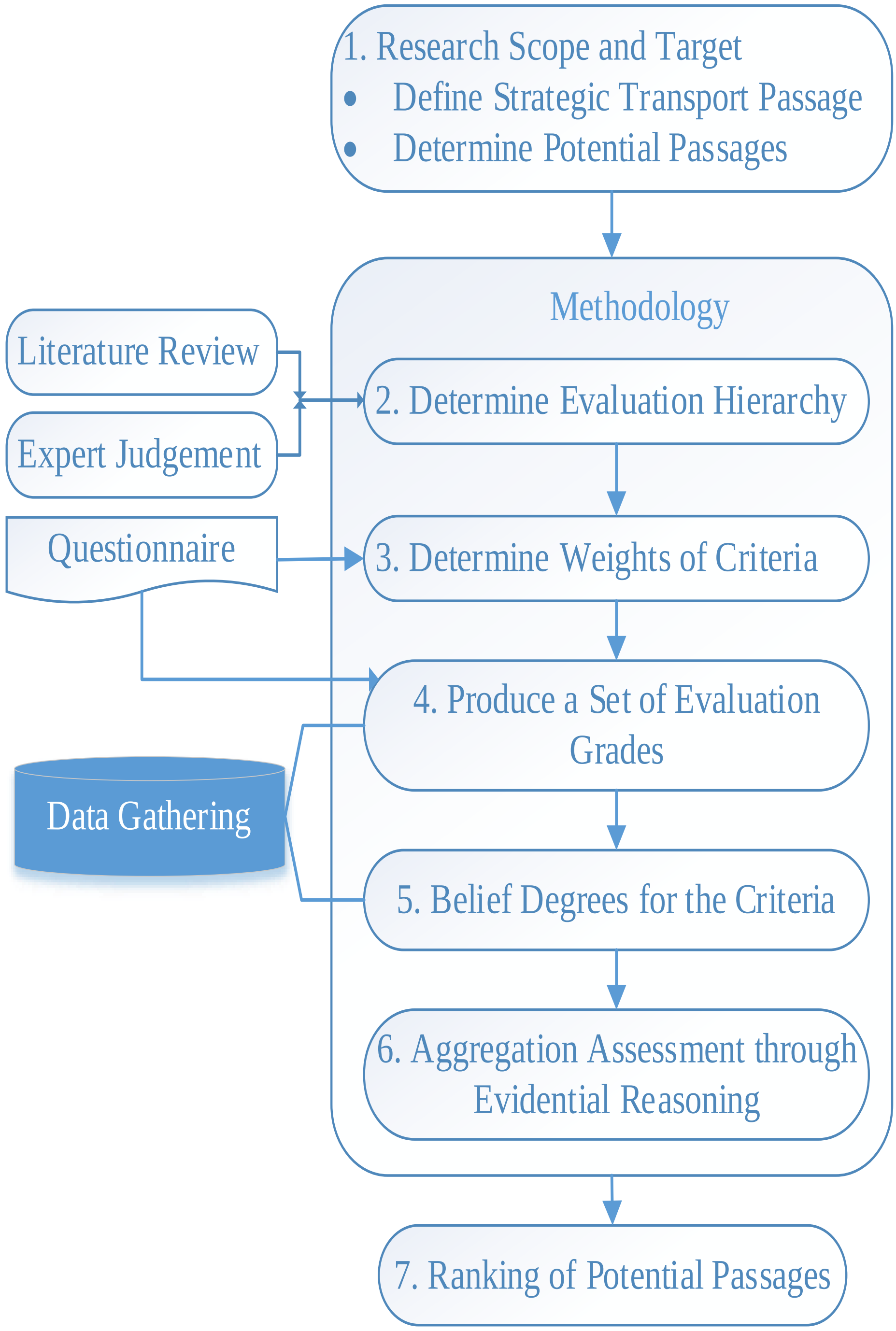

Figure 1. Methodological framework for identifying strategic transport passages.

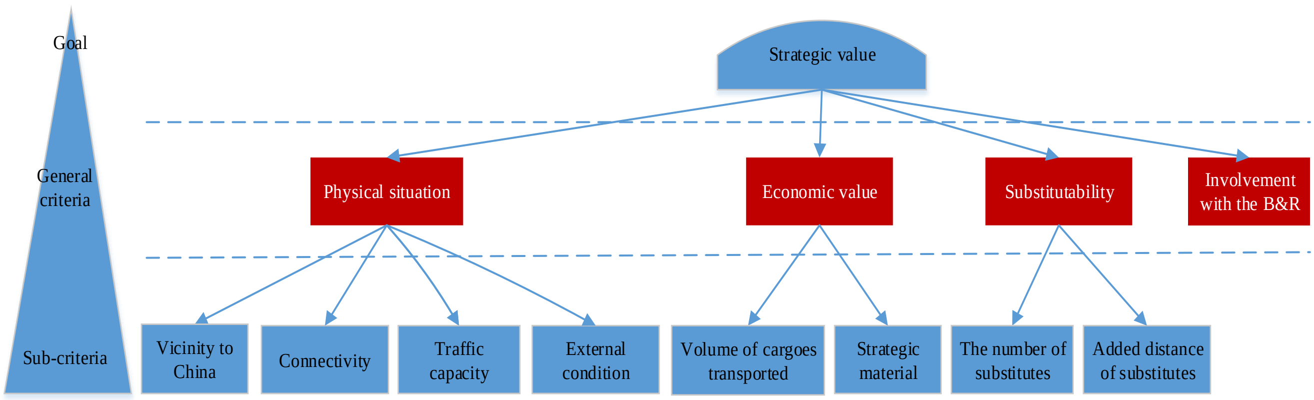

Figure 2. Evaluation hierarchy for strategic transport passages.

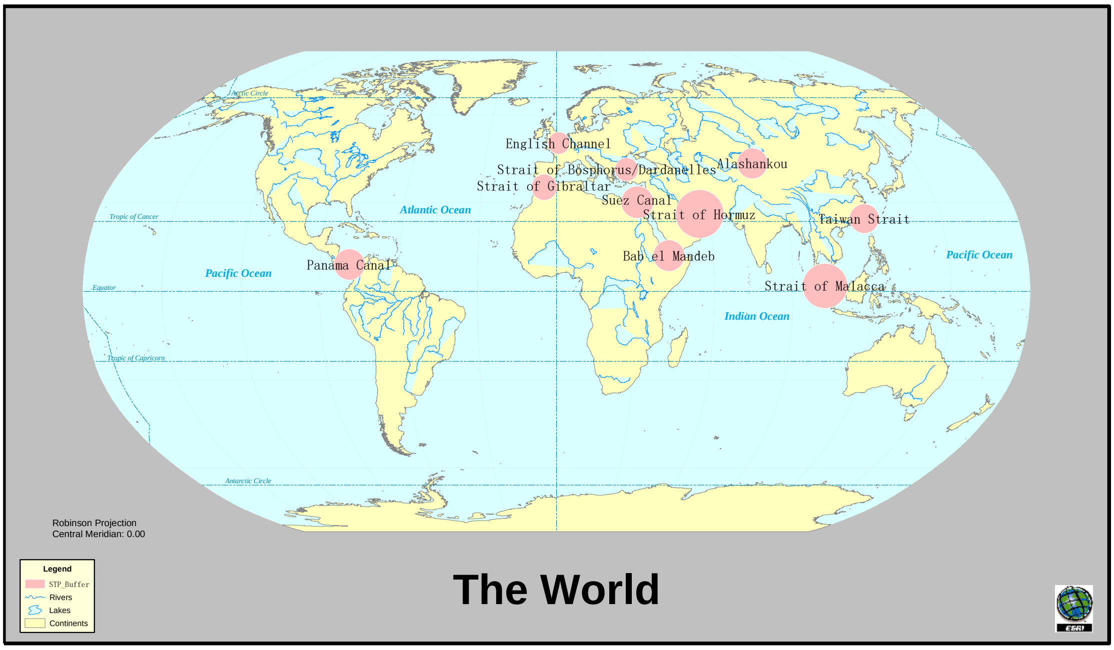

Figure 3. Geographic distribution of China’s top ten strategic transport passages.