# Priority analysis of port investment along the 21st-Century Maritime Silk Road region: The case of Southeast Asia

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## Abstract:

Most of the Southeast Asian countries are developing economies that have large demand for maritime infrastructures. Some but not all the ports in this region could significantly benefit from and contribute to the Belt and Road Initiative (BRI) proposed by the Chinese government. This paper models the port investment priority in the Southeast Asian region, so that efficient and sustainable investments can be made under the BRI. Based on the link prediction theory, a random walk method is proposed to assess the priorities of port construction projects at different sites. The method explicitly considers important economic and political factors, especially those linking the Southeast Asian countries with China. The model is calibrated and verified with numerical experiments so that policy and managerial recommendations can be obtained for the region. Results consistent with industry reality also provide supports to the validity of the model. This study introduces a new dimension of investment planning for multiple ports taking into account the resultant impacts on shipping networks, and recommends selected port construction sites with good potential in Southeast Asia.

**Keywords:** Maritime Silk Road; Port construction investment; Random walk; Southeast Asia

# 1 Introduction

In order to enhance the cooperation and connection with other countries, in 2013 the Chinese government proposed the initiative for the building of the "Silk Road Economic Belt" (SREB) and the "21st-Century Maritime Silk Road" (MSR), jointly referred to as the "Belt and Road Initiative" (BRI). The SREB links China with Europe through countries in Central Asia such as Kazakhstan and Turkmenistan, and Middle-eastern countries such as Iran and Iraq, as well as some other countries such as Russia and Ukraine. The MSR was initiated with the purpose of connecting China with the member countries in the Association of Southeast Asia Nations (ASEAN), and it stretches to Europe via the South China Sea and the India Ocean, further connected to the South Pacific Ocean via the South China Sea [*].

The main purpose of the BRI is to speed up the construction of infrastructure and improve interconnectivity with neighboring countries and regions (Brant, 2015). For this purpose, China has invested many infrastructure projects in various countries, especially in those countries along the BRI [†]. Transportation is the main driving force for economic development of a country, and transportation infrastructure is a significant foundation for the implementation of the BRI (Shao et al., 2018; Lau et al. 2018; Wang et al. 2020). The BRI had made large amount of investment on railway, highway and port construction. As one important transportation framework of the SREB, China Railway (CR) Express has become the third important transportation mode between China and Europe, in addition to maritime and air transportation. CR Express is building a bridge between China and BRI countries.

Maritime transportation is the major conduit of international trade, and ports play an important role in international cargo transportation. As mentioned before, one initial purpose of the MSR initiative is to connect China with the member countries in the ASEAN.  Since the launch of the BRI, many port construction projects invested by China have been launched in Africa [‡]. China has also invested in constructing ports in many other countries [§], including the Gwadar Port in Pakistan, the Piraeus Port in Greece, etc. In Southeast Asia, the Chinese government has invested a number of ports, including a few international hub ports such as the ports of Singapore, Pusan and

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[*] https://www.chinahighlights.com/silkroad/new-silk-road.htm

[†] http://www.yidaiyilu.gov.cn/wtfz.htm

[‡] http://mini.eastday.com/mobile/180109201555568.html

[§] http://www.ship.sh/news_detail.php?nid=26716

Kaohsiung (Chen et al., 2019). The Southeast Asian region has a huge development potential. Most Southeast Asian countries are developing countries, and the infrastructure construction and manufacturing industries are facing various challenges notably shortage of funds (Palit, 2017). The Coronavirus (COVID-19) pandemic has further exacerbated such problems. China has strong will and capacity for the investment in infrastructures. Southeast Asia is one of the most important regions for the global maritime industry, especially for cargo shipments between Asia and Europe. Improvements in port infrastructure can also significantly enhance the development of transportation and economic activities the region. In 2020, China invested 17.79 billion US dollars in countries along the BRI, 18.3% higher than that in 2019 [**]. Hence more port investments in Southeast Asia can be expected as part of the efforts implementing the MSR initiative. Despite such huge investments, due to huge capital involved in port investment (especially when multiple ports are involved), it is impractical to invest in all ports in a region or along a shipping network. Furthermore, it is important to ensure the sustainability of the projects thus that both the Southeast Asian nations and the BRI can be successful in the long term with win-win outcomes. This gives rise to an important and pressing problem on how to make efficient and sustainable investments into ports. As elaborated below in the literature review, most port investment studies focused on individual port and project. In comparison, our study deals with a port investment priority problem, with an aim to rank the projects based on also their contribution to the BRI and associated shipping networks. That is, our study introduces a new dimension to the port investment literature in that network effects and system considerations are explicitly considered in the project priority ranking. Such an improvement could have important managerial and policy implications..

### 1.1 Literature review

Many studies have investigated the issues related to port investments. A number of them focused on the “construction” issues in that they focused on the technical planning and operations problems. For example, a number of researchers (Liu et al., 2010; Zheng et al., 2011; Chen et al., 2018; Li et al., 2019) studied the environmental issues during the construction of a single port. By considering different environmental areas, Liu et al. (2010) investigated the ecological compatibility between port construction and wetland ecosystem. Zheng et al. (2011) focused on

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[**] http://www.yidaiyilu.gov.cn/xwzx/gnxw/163244.htm

identifying the environmental risks during the period of port construction. Similarly, with respect to the ecological risks in Yangshan port, Li et al. (2019) aimed to evaluate the remediation effectiveness of ecological restoration during the transition period from port construction to operation. According to the ecological technologies, Chen et al. (2018b) addressed the port reclamation construction problem. Zhu (2011) and Gabriel et al. (2017) focused on the management of working days during port construction.

More studies have examined investment strategy and planning. For example, many researchers investigated the effects of port competition and to cooperation within a region, mostly based on game theory (Xiao et al. 2012; Luo et al., 2012; Liu et al. 2013; Zhuang et al. 2014; Chen and Liu, 2016; Wan et al., 2016; Cheng and Yang, 2017; Wang and Zhang, 2018; Balliauw et al., 2019; Randrianarisoa and Zhang, 2019). Using to a two-stage game, Chen and Liu (2016) studied the facility investments of two ports by considering port competition under congestion and uncertain demand. The port investment equilibrium was mainly analyzed. Similarly, Cheng and Yang (2017) discussed Nash equilibrium for port investment on multiple ports within a region. In an uncertain environment, Balliauw et al. (2019) studied Cournot equilibrium on capacity investment decisions of two competing ports. For two ports and a common inland, which are belonged to three independent regional governments, Wan et al. (2016) addressed landside port accessibility investment in terms of the decisions of the port governments and inland government. To enhance network resilience by using a network game theory approach, Chen et al. (2018a) explored strategic investment for a port-hinterland container transportation network. Xiao et al. (2015), Wang and Zhang (2018) and Randrianarisoa and Zhang (2019) further investigated the effects of climate change on port investment, taking into account of possible competition between ports. A few recent studies further extended the setting to the vertical market structure, thus that the behaviors of shipping company – port is also formally recognized (Zhu et al. 2019; Jiang et al. 2021).

These studies offer rich insights and practical recommendation. However, virtually all of them have focused on the analysis of individual port, or multiple ports within a port cluster. This is not the case for the BRI, when multiple ports along the belt region (and also inter-continental shipping networks) need to be considered. Indeed, recently quite a few studies have been carried out on the BRI (Liu, et al., 2018; Shao, et al., 2018; Sheu and Kundu, 2018; Yang, et al., 2018a, 2018b; Zeng, et al., 2018; Kundu and Sheu, 2019; Sun, et al., 2019; Wen, et al., 2019). Schinas and Westarp

(2017) discussed the impacts of the MSR initiative on the existing liner shipping services, including ship fleet, port throughput, and carbon footprint. Based on 18 factors related to condition (C), capacity (C), potential (P) and efficiency (E), Peng et al. (2018) proposed a comprehensive CCPE model to determine port competitiveness along the MSR region. Chen and Yang (2018) investigated the impacts of BRI on port clusters along the MSR region, by considering industry transfer and production capacity constraints. Chan and Reiner (2019) studied the value chain governance in the transport biofuel sector along the MSR region. That is, the needs of considering multiple ports across countries, preferably in connection with shipping networks, have already been identified in the literature. Yet, few port investment studies have incorporated them into modelling analysis. This study aims to fill this gap in research.

### 1.2 Contributions in modelling and insights.

In order to assess the priorities of port investments in multiple sites across different countries alone shipping networks, we borrow the idea from the link prediction problem (Lü and Zhou, 2011), which was developed to determine the likelihood of the existence of the missing links. As an extension of the original link prediction problem, our analysis aims to determine the likelihood of the existence of the potential nodes (i.e. seaports in our analysis). Lü and Zhou (2011) provided a survey on some physical approaches such as random walk methods and maximum likelihood methods applied in link prediction. Because of the main difference between our analysis and the typical link prediction problem, most approaches on link prediction cannot be directly applied. As elaborated below, we propose a port evaluation method based on the random walk method, where many practical factors are incorporated, notably the economic and political factors that link Southeast Asian countries with China. For ease of notation, this port evaluation method is still referred to as a random walk method.

To the best of our knowledge, the only similar study on transport infrastructure investment is the recent work by Shao et al. (2018), which examined high-speed railway construction priority in the BRI region. There are however some significant differences between our method and that used in Shao et al. (2018): Firstly, Shao et al. (2018) aims to find the proper road sections within the generated high-speed railway transportation network, while our random walk method aims to find the proper sites selected from the potential ports in our generated physical shipping network for port construction investment. Since multiple routes may be linked to one specific ports, more scenarios need to be considered in our study. Secondly, Shao et al. (2018) fictitiously connect different cities in the BRI region. In practice, not all city-pairs can be connected by high-speed railway, especially when two cities are located in different countries. In comparison, our study models a physical shipping network connecting to real ports, the potential ports and the dummy nodes. The shipping network is generated based on the practical and physical waterways, as shown in Figure 1.

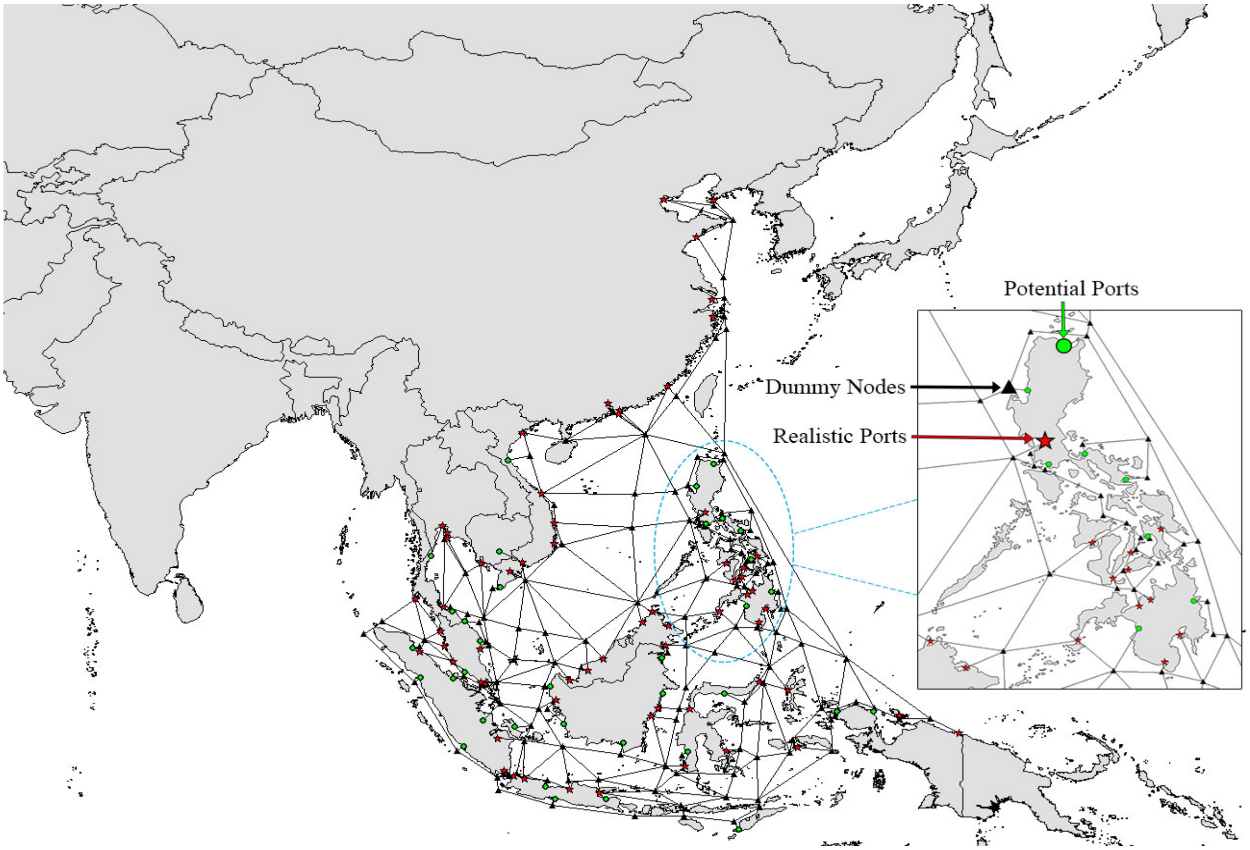

Fig. 1 A physical shipping network with the realistic ports, the potential ports and the dummy nodes for shipping cargoes between China and Southeast Asia.

Finally, and most importantly, the core of Shao et al. (2018) is based on shortest path problem solved with the Dijkstra algorithm, while our method is based on the random walk method, a sophisticated method on link prediction (Liu and Lü, 2010; Lü and Zhou, 2011; Song, et al., 2019; Curado, 2020). Note that the shortest path problem is not proper for solving our problem, because any port (the realistic port or the potential port) is a leaf node in our generated physical shipping network, as shown in the inset of Figure 1. As a result, instead of routing through other ports, the shortest path between two ports will mostly likely pass through the dummy nodes, which are the best potential entry points to waterways. As shown in Section 2 and the inset of Figure 1, a port is connected to waterway via a dummy node, and the shortest path between any two ports will make a detour when passing through other ports.

In summary, the contributions of this paper are multi-fold. Firstly, a port investment priority problem is formulated in order to explore the priorities of port investment at different sites along the BRI region, with a focus on Southeast Asia. Shipping network is explicitly considered in the analysis, while the resultant port investment choices would have significant impacts on the (future) shipping network. That is, shipping network is endogenously considered in the analysis. This is a different approach compared to existing port investment studies as reviewed above. A most basic project evaluation tool would have simply required the (present value) of benefit is greater than investment cost, or the ratio of return to investment is greater than 1, for the chosen port. This clearly does not apply to the BRI, as the investor (i.e. Chinese government) needs to consider the optimal resource allocation across multiple countries along the maritime shipping network. That is, multiple ports and their (future) impacts on shipping network are considered. The game theory approach adopted for investigating the effects of the competition between different ports is not suitable for solving our problem neither, because there is only one investment decision-maker (i.e. China or the BRI), rather than multiple stakeholders or rivals. Secondly, a random walk method is adapted, which explicitly considers economic and political factors linking Southeast Asian countries with China. Finally, the proposed model can be used to analyze a range of practical questions. Section 4 provides a number of numerical experiments in the context of BRI. More generally, all major shipping lines have been investing in port and terminal operators. Zhu et al. (2018) reviewed the vertical port investments by the world's top 10 container shipping lines. Other than the Hamburg Sud Group, all of them have established port and terminal operators. The APM Terminals, a sister company of the APM-Maersk, managed 73 terminals as of 2018. These shipping lines face the same problem considered in our study, in that they need to consider multiple ports alone their (future) shipping networks. In summary, our study offers both methodological and managerial contributions to solve important issues in the maritime industry.

The rest of this paper is organized as follows. Section 2 provides notations, indices and problem description. A random walk method is presented in Section 3. Numerical experiments are carried out in Section 4. Finally, Section 5 summarizes and concludes.

## 2 Notations, indices and problem description

### 2.1 Realistic ports, potential ports and dummy nodes

This paper aims to model the port investment priority in the Southeast Asian region, which has a huge development potential and is of strategic importance to the BRI. Moreover, it was one initial purpose of the MSR initiative to connect China with the member countries in the ASEAN.

As shown in Figure 1, we consider many realistic ports and the potential sites for constructing ports in the Southeast Asian region. The potential sites are called the potential ports. Meanwhile, we also consider many dummy nodes, via which the realistic ports and the potential ports can be connected to waterways, as illustrated in the inset of Figure 1. Let $P_r$ denote a set of the realistic ports, let $P_p$ be a set of the potential ports and $P_d$ be a set of the dummy nodes. Consider a simple shipping network $G(N,E)$, where $N = P_r \cup P_p \cup P_d$ is the set of nodes and $E$ is the set of links. In this paper, we aim to identify the priorities of investment for different potential ports/sites, and we propose a port evaluation method considering the relationship between China and Southeast Asia. To proceed, different sets are used to represent the candidate ports in China and Southeast Asia, respectively. Namely, let $P_c$ denote a set of considered ports in China, and let $P_s$ be a set of considered ports in Southeast Asia. Clearly, we have $P_c \cup P_s = P_r \cup P_p$ . In order to properly determine the priorities of port construction investment at different sites, we consider many indices, which are discussed below.

### 2.2 Port economic condition index and port comprehensive cooperation index

For any realistic or potential port $j$ ($\forall j \in P_s$) located in city (or province) $m$ of Southeast Asian country $k$, let the port economic condition index (denoted by $ec_j$) represent the economic development level of city $m$ hosting port $j$, which can be defined as

$$ec_j = \sigma_1 G_k + \sigma_2 g_m, \forall j \in P_s \tag{1}$$

where $G_k$ is the Gross Domestic Product (GDP) index of Southeast Asian country $k$ and $g_m$ is the Gross Regional Domestic Product (GRDP) index of city $m$. $\sigma_1$ and $\sigma_2$ ($0 < \sigma_1 < \sigma_2 < 1$) are two parameters. Here we consider $\sigma_1 = 0.4$ and $\sigma_2 = 0.6$. The data of GDP and GRDP can be obtained from the websites of the World Bank Group [††] and the National Bureau of Statistics of the Southeast Asian countries.

Let the port comprehensive cooperation index (denoted by $cc_j$) represent the level of cooperation between China and the city hosting port $j$ ($\forall j \in P_s$) located in Southeast Asian country $k$. To determine this index, we mainly consider the political stability index of Southeast Asian country $k$ (denoted by $ps_k$), the port economic condition index ($ec_j$), and the national cooperation evaluation index of Southeast Asian country $k$ with China (denoted by $ce_k$), following the Yearbook of China's Belt and Road Initiative Editorial Committee (2017). Then we have

$$cc_j = \left(1 + ps_k\right)\left(\alpha_1 ce_k + \alpha_2 ec_j\right), \forall j \in P_s \tag{2}$$

where $\alpha_1$ and $\alpha_2$ ($0 < \alpha_2 < \alpha_1 < 1$) are two parameters. Here we consider $\alpha_1 = 0.6$ and $\alpha_2 = 0.4$. According to the Yearbook of China's Belt and Road Initiative Editorial Committee (2017), we can obtain the national cooperation evaluation index $ce_k$. For a stable Southeast Asian country $k$, we have

$$ps_k \to 1 \tag{3}$$

### 2.3 National trade demand index and weighted transportation efficiency

For any country $k$ in Southeast Asia, let the national trade demand index (denoted by $td_k$) represent the level of trade demand to be generated between China and Southeast Asian country $k$. To determine this index, we mainly consider the bilateral trade index of Southeast Asian country $k$ with China (denoted by $bt_k$) and the industrial structure complementarity index of Southeast Asian country $k$ with China (denoted by $isc_k$), following the Yearbook of China's Belt and Road Initiative Editorial Committee (2017). Then we have

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[††] https://data.worldbank.org.cn

$$td_k = \beta_1 bt_k + \beta_2 isc_k \tag{4}$$

where $\beta_1$ and $\beta_2$ ($0 < \beta_2 < \beta_1 < 1$) are two parameters. Here we consider $\beta_1 = 0.6$ and $\beta_2 = 0.4$. According to the Yearbook of China's Belt and Road Initiative Editorial Committee (2017), we can obtain the indices $bt_k$ and $isc_k$.

Following Latora and Marchiori (2001), the transportation efficiency ($te_{ij}$) between two ports ($i$ and $j$) located in China and the Southeast Asian region, can be defined as follows:

$$te_{ij} = \frac{1/Dis_{ij}}{\sum_{k \in P_c} \sum_{m \in P_s} \left(1/Dis_{km}\right)} \tag{5}$$

where $Dis_{ij}$ is the shortest distance between $i$ and $j$. When transporting cargoes between different countries, the transportation efficiency is not only related to the shortest distance from the origin node to the destination node, but is also related to the features of different countries. Here, we introduce the weighted transportation efficiency by considering the tariff level index of Southeast Asian country *k* with China (denoted by $tl_k$), the non-tariff barrier index of Southeast Asian country *k* with China (denoted by $ntb_k$) and the logistics performance index of Southeast Asian country *k* (denoted by $lp_k$), following the Yearbook of China's Belt and Road Initiative Editorial Committee (2017). Then we have,

$$te'_{ij} = \left(1 + \theta_k\right) te_{ij} \tag{6}$$

where $\theta_k$ is a weighted coefficient, and it can be calculated as follows:

$$\theta_k = \mu_1 tl_k + \mu_2 ntb_k + \mu_3 lp_k \tag{7}$$

where $\mu_1$, $\mu_2$ and $\mu_3$ are three parameters. Here we consider $\mu_1 = 0.3$, $\mu_2 = 0.3$ and $\mu_3 = 0.4$. According to the Yearbook of China's Belt and Road Initiative Editorial Committee (2017), we can obtain the indices $tl_k$, $ntb_k$ and $lp_k$.

### 2.4 Port attraction evaluation index

In this paper, a random walk method is proposed to determine the priorities of port construction investment at different sites, as will be shown later. Here we mainly consider a port attraction evaluation index (denoted by $ae_{ij}$), which is the most important index considered in this paper. This index is used in our random walk method for determining the origin-destination (OD) association for each random walker.

To determine the index $ae_{ij}$, we mainly consider the port comprehensive cooperation index, the national trade demand index, and the weighted transportation efficiency. For any port $i$ in China and any port $j$ in Southeast Asian country $k$, we have

$$ae_{ji} = ae_{ij} = BRp_m\left(\gamma_1 cc_j + \gamma_2 td_k + \gamma_3 te'_{ij}\right), \forall i \in P_c, \forall j \in P_s \tag{8}$$

where $\gamma_1$, $\gamma_2$ and $\gamma_3$ are three parameters. Here we mainly consider $\gamma_1 = 0.6$, $\gamma_2 = 0.3$ and $\gamma_3 = 0.1$, unless pointed out specifically. $BRp_m$ refers to the participation level index of city $m$ hosting Chinese port $i$ in the BRI.

According to The Belt and Road Initiative Big Data Center at the State Information Center of China (2016), we can obtain the index $BRp_m$. As shown in The Belt and Road Initiative Big Data Center at the State Information Center of China (2016), the index $BRp_m$ is mainly correlated with five factors: the policy environment index, the facility supporting index, the economic and trade cooperation index, the cultural and educational exchange index, and the comprehensive influence index. In addition, we assume

$$ae_{ji} = ae_{ij} \equiv 0, \forall i, j \in P_c \tag{9}$$

$$ae_{ji} = ae_{ij} \equiv 0, \forall i, j \in P_s \tag{10}$$

### 2.5 Problem description

According to the current situations along the MSR, including the international economic and political factors (e.g., the national cooperation level of Southeast Asian countries with China), this paper aims to investigate the priorities of port construction investment at different sites in the Southeast Asian region. Namely, we aim to determine the priority order of port construction investment for the potential ports located in the Southeast Asian region. Note that, our studied problem is completely different from the hub location problem (Alumur and Kara, 2008; Campbell and O'Kelly, 2012; Zheng, et al., 2018, 2019), which mainly aims to find the optimal hub locations by minimizing the total cost for transporting cargoes from their origin nodes to their destination nodes.

As will be shown below, we propose a practical and effective port evaluation method to assess the feasibility of port construction investment. Actually, we borrow the idea from the random walk methods on link prediction (Liu and Lü, 2010; Lü and Zhou, 2011; Song, et al., 2019; Curado, 2020). Different from the previous random walk methods, our method explicitly incorporate the economic and political factors of Southeast Asian countries, especially those linked with China, as elaborated above. In addition, we consider the OD pair generated for each random walker when walking between China and Southeast Asia. The port attraction evaluation index is used to determine the OD association for each random walker, as explained in details below.

## 3. Random walk method

Given a simple network $G(N,E)$, the random walk method can be described by using a Markov chain, which determines the sequence of nodes visited by each random walker. For any random walker $x$, this process can be described by a Markov transition matrix $P^x$, where its component $p_{ij}^x$ represents the probability that random walker $x$ staying at node $i$ will move to node $j$ in the next time step. Different from the previous random walk methods (Tong, et al., 2008; Liu and Lü, 2010; Lü and Zhou, 2011; Mantrach, et al., 2011; Masuda, et al., 2017; Song, et al., 2019; Curado, 2020), we generate an OD pair for each random walker, according to the port attraction evaluation index. The details will be shown in the procedure of our random walk method. We further consider that, each random walker staying at the current node $i$ will move to one of its neighbor nodes with a probability proportional to the shortest distance between the neighbor node and the destination node. Let $D_x$ denote the destination port of random walker $x$. If $(i,D_x)\in E$, we have $p_{iD_x}^x=1$, otherwise $p_{ij}^x$ is defined as follows:

$$p_{ij}^x=\begin{cases}\dfrac{1/Dis_{jD_x}}{\sum_{(i,k)\in E}\left(1/Dis_{kD_x}\right)}, & \text{if } (i,j)\in E;\\ 0, & \text{otherwise.}\end{cases} \tag{11}$$

For any random walker $x$, we have

$$\sum_{(i,j)\in E} p_{ij}^x=1, \forall i\in N \tag{12}$$

Given the maximum time step denoted by $T$, the procedure of our random walk method can be described as follows:

Step 1. (Initialization): Calculate the port attraction evaluation index, and set the maximum time step $T$. Set the initial time step $t = 0$. We consider $|P_c \cup P_s|$ random walkers starting from all realistic and potential ports, which can be regarded as their origin ports. For each random walker, randomly select a destination port associated with the origin port, by considering a probability proportional to the port attraction evaluation index. Actually, for any origin port in China (Southeast Asia), we will choose a destination port in Southeast Asia (China). When choosing the destination port for any origin port $i$ ($\forall i \in P_c \cup P_s$), assume that the probability $\pi(j)$ that the destination port $j$ is chosen for origin port $i$ depends on the port attraction evaluation index ($ae_{ij}$), in such a way that:

$$\pi(j) = \frac{ae_{ij}}{\sum_{k \in P_c \bigcup P_s} ae_{ik}}, \forall j \in P_c \bigcup P_s \tag{13}$$

Step 2. (Loop): Let $t = t + 1$, and update the movement of each random walker according to the Markov transition matrix. The movement process is recorded. If there are certain random walkers arriving at their destination ports, go to step 3. Otherwise, go to step 4.

Step 3. (New random walker generation): For each random walker arriving at its destination port, randomly select a new origin port from the realistic or potential ports, and then the random walker will restart moving from the new origin. An associated destination port is further selected with respect to the probability based on Eq. (13). Go to step 4.

Step 4. (Stopping criterion): If $t = T$, then terminate, and output the solution. Otherwise, go to step 2.

## 4 Numerical experiments

### 4.1 Data description

In this section, we provide numerical results to account for the effectiveness of our random walk method, by considering a physical shipping network, as shown in Figure 1. The realistic and potential ports considered here are obtained based on World Port Map (2019), where 9 major realistic ports in China and 54 realistic ports in Southeast Asia are mainly considered, as shown in

Figure 1 and Table 1. For the considered Chinese ports, most of them are among the top 10 ports in terms of port throughput. In order to explore the priorities of port construction investment at different sites, we consider 35 potential ports in Southeast Asia, as shown in Figure 1 and Table 2.

Table 1 Considered realistic ports in China and Southeast Asia.

| No. | Port | Province/City | No. | Port | Province/City |
|---|---|---|---|---|---|
| 1 | Shanghai | Shanghai | 6 | Qingdao | Shandong |
| 2 | Shenzhen | Guangdong | 7 | Tianjin | Tianjin |
| 3 | Ningbo | Zhejiang | 8 | Xiamen | Fujian |
| 4 | Hong Kong | Hong Kong | 9 | Dalian | Liaoning |
| 5 | Guangzhou | Guangdong | | | |
| 1 | Singapore | Singapore | 28 | Sattahip | Chonburi |
| 2 | Jakarta | Jakarta | 29 | Phuket | Phuket |
| 3 | Semarang | Central Java | 30 | Songkhla | Songkhla |
| 4 | Belawan | North Sumatra | 31 | Laem Chabang | Chonburi |
| 5 | Balikpapan | East Kalimantan | 32 | Manila | Capital Region |
| 6 | Samarinda | East Kalimantan | 33 | Cebu | Central Visayas |
| 7 | Suralaya | Banten Province | 34 | Iloilo | West Visayas |
| 8 | Palembang | South Sumatra | 35 | Tacloban | East Visayas |
| 9 | Panjang | West Sumatra | 36 | Tagbilaran | Central Visayas |
| 10 | Jayapura | Papua | 37 | Dumaguete | Central Visayas |
| 11 | Biak | Papua | 38 | Iligan | North Mindanao |
| 12 | Pontianak | West Kalimantan | 39 | Zamboanga | Zamboanga Peninsula |
| 13 | Pantoloan | Central Sulawesi | 40 | Davao | Davao |
| 14 | Bitung | North Sulawesi | 41 | Cagayan de Oro | North Mindanao |
| 15 | Kendari | Southeast Sulawesi | 42 | General Santos | South Cossang |
| 16 | Ambon | Maluku | 43 | Penang | Penang |
| 17 | Makassar | South Sulawesi | 44 | Lumut | Perak |
| 18 | Ternate | North Maluku | 45 | Port Kelang | Selangor |
| 19 | Surabaya | East Java | 46 | Kuantan | Pahang |
| 20 | Hai Phong | Haiphong | 47 | Kuching | Sarawak |
| 21 | Da Nang | Da Nang | 48 | Sibu | Sarawak |
| 22 | Quy Nhon | Binh Dinh | 49 | Tanjong Kidurong | Sarawak |
| 23 | Nha Trang | Khanh Hoa | 50 | Kota Kinabalu | Sabah |
| 24 | Can Tho | Can Tho | 51 | Kudat | Sabah |
| 25 | Ho Chi Minh | Ho Chi Minh | 52 | Sandakan | Sabah |
| 26 | Sihanoukville | Sihanoukville | 53 | Tawau | Sabah |
| 27 | Bangkok | Bangkok | 54 | Tanjung Pelepas | Johor |

Table 2 The potential ports in Southeast Asia.

| No. | Port | Province/City | Country | No. | Port | Province/City | Country |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | Parepare | South Sulawesi | Indonesia | 19 | Tarakan | East Kalimantan | |
| 2 | Pemangkat | West Kalimantan | | 20 | Nghe Tinh | Ha Tinh | Vietnam |
| 3 | Dumai | Riau | | 21 | Nam Can | Ca Mau | |
| 4 | Kupang | East Nusa Tenggara | | 22 | Phnom Penh | Phnom Penh | Cambodia |
| 5 | Ketapang | West Kalimantan | | 23 | Bang Saphan | Prachuap Khiri Khan | Thailand |
| 6 | Cirebon | West Java | | 24 | Pattani | Pattani | |
| 7 | Banjarmasin | South Kalimantan | | 25 | Aparri | Cagayan Valley | Philippines |
| 8 | Gorontalo | North Sulawesi | | 26 | San Fernando | Ilocos | |
| 9 | Manokwari | West Papua | | 27 | Batangas | Alabathon | |
| 10 | Pangkalan Susu | North Sumatra | | 28 | Jose Panganiban | Bicol | |
| 11 | Bengkulu | Bengkulu | | 29 | Legaspi | Bicol | |
| 12 | Probolinggo | East Java | | 30 | Isabel | East Visayas | |
| 13 | Sibolga | North Sumatra | | 31 | Polloc Harb | Mindanao Muslim Autonomous Region | |
| 14 | Sorong | West Papua | | 32 | Bislig | Caraga | |
| 15 | Jambi | Jambi | | 33 | Melaka | Malacca | Malaysia |
| 16 | Cilacap | Central Java | | 34 | Kota Bharu | Kelantan | |
| 17 | Tanjung Bara | East Kalimantan | | 35 | Kerteh | Terengganu | |
| 18 | Pangkalbalan | Bangka-Belitung | | | | | |

For the maximum time step $T$ within our random walk method, we mainly set $T = 400000$, where the last 200000 time steps are used to calculate the indices in the following. Our random walk method is coded by using Visual C++, which runs on a 3.5 GHz Dual Core desktop PC with the Windows 7 operating system and 8 GB of RAM. Our random walk methods can be solved within several minutes for different cases.

### 4.2 Validation of our random walk method

In order to explore the priorities of port construction at different sites, we present an port investment evaluation index, which can be regarded as the investment probability of any port (denoted by $Ip_i$) with respect to its attraction from the perspective of random walkers. Here, the investment probability of any port $i$ ($\forall i \in P_c \cup P_s$) is defined by the normalized number of times of this port to be visited by all random walkers,

$$Ip_i = \frac{Num_i}{\max\{Num_j, j \in P_c \bigcup P_s\}}, \forall i \in P_c \bigcup P_s \tag{14}$$

where $Num_i$ denotes the number of times of port $i$ ($\forall i \in P_c \cup P_s$) to be visited by all random walkers during the considered time period.

As mentioned in Section 2, this paper defines the port attraction, based on the economic condition, the trade demand, etc. Because of the large port throughput, the considered Chinese ports may have a relatively high attraction, as compared with other considered ports. Moreover, the realistic ports have a relatively high attraction, as compared with the potential ports. In order to verify our random walk method, three different scenarios (Scenario I, Scenario II and Scenario III) are tested by slightly changing Step 3 in our random walk method. In Scenario I, we consider that the new origin port is randomly selected from the considered Chinese ports when any random walker arrives at the destination port. In Scenario II, the new origin port is randomly selected from the considered ports (the realistic ports and the potential ports) in Southeast Asia. In Scenario III, the new origin port is randomly selected from all considered ports. The results of different scenarios are summarized in Figure 2. As shown in Figure 2(a), the considered Chinese ports have a relatively large attraction (investment probability) in Scenario I. However, for most realistic ports in Southeast Asia, their attractions are similar to those of the potential ports in this scenario. In Scenario II and Scenario III, the attractions of most realistic ports are larger than those of the potential ports. However, the attractions of the considered Chinese ports are similar to those of the realistic ports in Southeast Asia in these two scenarios. In order to combine the advantages of these three scenarios, we further present another scenario, i.e., Scenario IV. In Scenario IV, we consider that the new origin port is selected from the considered Chinese ports with a probability $p^c$. Figure 2(d) typically shows the results for $p^c = 0.5$. As shown in Figure 2(d), the considered Chinese ports have a relatively large attraction in this scenario. Moreover, the investment probabilities (attractions) of most realistic ports are larger than 0.2, and some of them are larger than 0.4. While for the potential ports, most of their investment probabilities are smaller than 0.2, and many of them are around 0.1. Our results can validate the feasibility and effectiveness of our method in this scenario. Next, we further validate our method based on Scenario IV (see Figures 3 and 4), and Subsection 4.3 shows more results in this scenario, in order to further explore the investment probabilities of the potential ports in Southeast Asia.

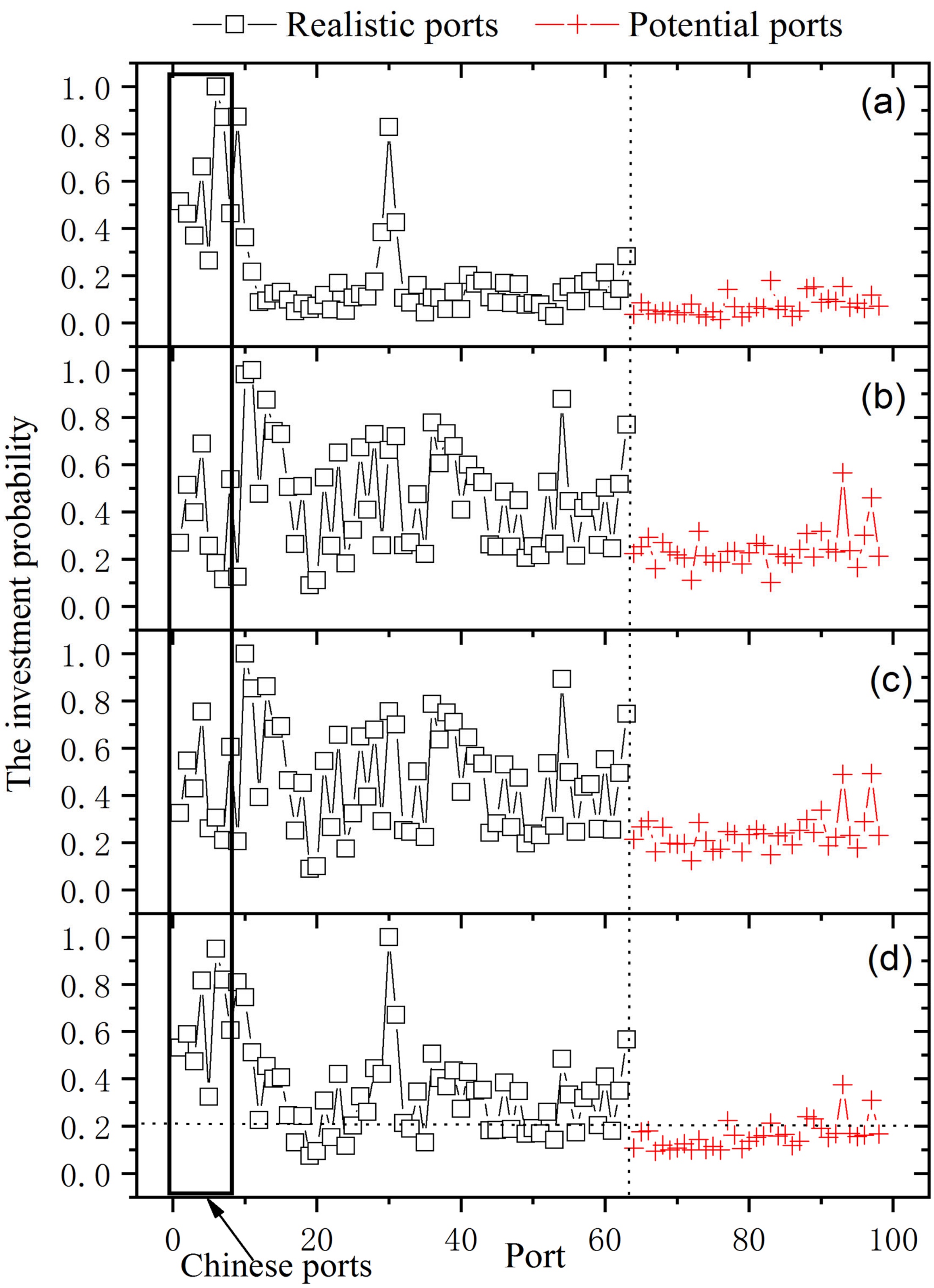

Fig. 2 The investment probabilities of the realistic and potential ports for (a) Scenario I, (b) Scenario II, (c) Scenario III, and (d) Scenario IV.

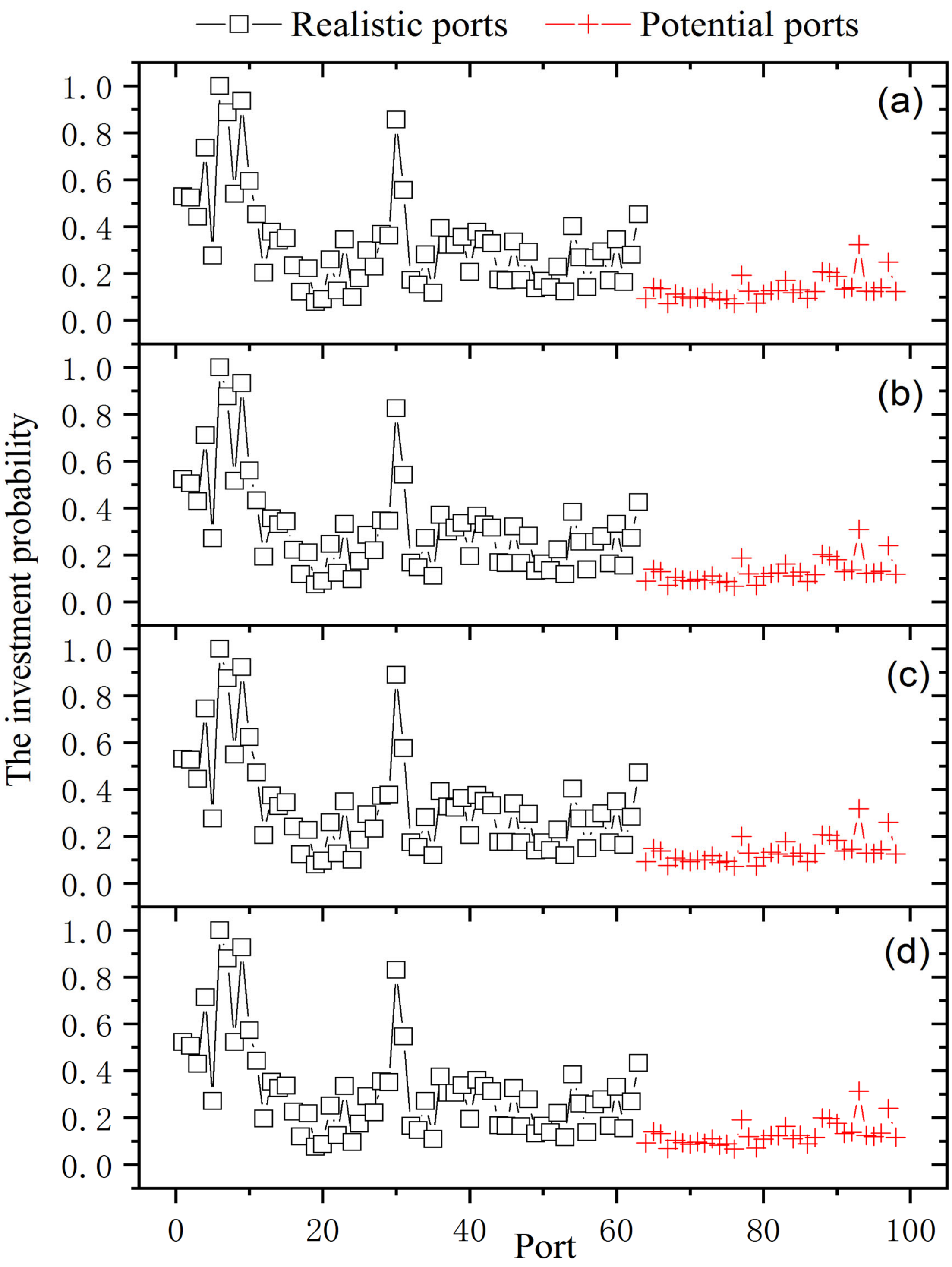

Fig. 3 The investment probabilities of the realistic and potential ports for (a) $\gamma_1 = 0.1$, $\gamma_2 = 0.6$, $\gamma_3 = 0.3$, (b) $\gamma_1 = 0.3$, $\gamma_2 = 0.1$, $\gamma_3 = 0.6$, (c) $\gamma_1 = 0.6$, $\gamma_2 = 0.3$, $\gamma_3 = 0.1$, and (d) $\gamma_1 = 0.333$, $\gamma_2 = 0.333$, $\gamma_3 = 0.333$.

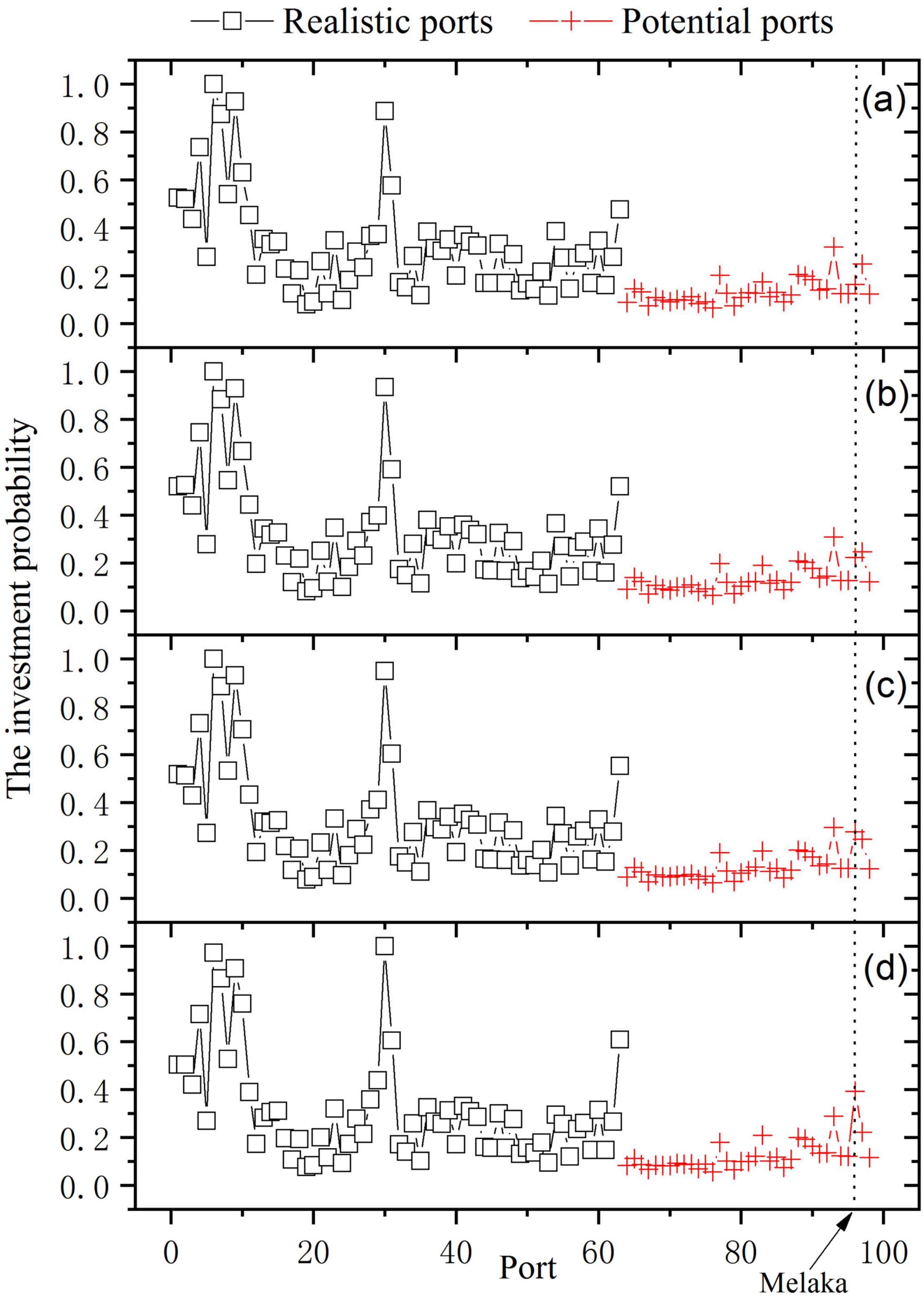

Fig. 4 The investment probabilities of the realistic and potential ports for (a) $\eta = 5$, (b) $\eta = 20$, (c) $\eta = 50$, and (d) $\eta = 500$.

As mentioned in Section 2, the port attraction evaluation index is the most important index considered in the analysis, and three parameters ($\gamma_1$, $\gamma_2$ and $\gamma_3$) are considered when calculating this index. Figure 3 shows the results for different values of these three parameters, in order to further validate our method based on Scenario IV. Clearly, similar results can be obtained for different values of $\gamma_1$, $\gamma_2$ and $\gamma_3$. In other words, our results are very stable.

As shown in Figure 1, we only consider a physical shipping network within the Southeast Asian region. The MSR also links China with Middle-eastern countries and Europe, etc. In order to further validate our method by considering the effect of ports in Middle-eastern countries and Europe, we introduce a dummy port (denoted by DP). We introduce a link between dummy port DP and Melaka into our considered physical shipping network (Figure 1). If we introduce big values for measuring the port attraction evaluation index associated with dummy port DP, and then dummy port DP can be used to represent the ports in Middle-eastern countries and Europe. For simplicity, we define the port attraction evaluation index associated with dummy port DP, as follows

$$ae_{DP,i} = ae_{i,DP} = \eta \cdot \max_{j \in P_s} \left\{ ae_{ij} \right\}, \forall i \in P_c \tag{15}$$

where $\eta$ is a parameter. Figure 4 shows our results for different values of $\eta$. Clearly, with the increase of $\eta$, the investment probability of Melaka increases significantly. We can infer that, as compared with other considered potential ports in Southeast Asia, Melaka has more advantages for port construction investment when we consider the physical shipping network between Asia and Europe. In practice, China has indeed invested port construction in Malacca (Chen et al., 2019). These results consist with our modelling results can also partly support the rationality of our random walk method. In the following, we show more results for exploring the investment probabilities of the potential ports in Southeast Asia.

### 4.3 More results on the potential ports

In order to clearly show the investment probabilities of different potential ports, here the investment probability is renormalized as

$$Ip_i = \frac{Num_i}{\max\{Num_j, j \in P_p\}}, \forall i \in P_p \tag{16}$$

Firstly, we focus on exploring the properties of the investment probabilities of all considered potential ports. Here we consider the cumulative investment probability distribution (denoted by $P(>Ip)$), which can be defined as follows:

$$P(>Ip)=\frac{n_{Ip}}{|P_p|} \tag{17}$$

where $n_{Ip}$ represents the number of the potential ports whose investment probabilities are larger than $Ip$, and $|P_p|$ is the number of the potential ports.

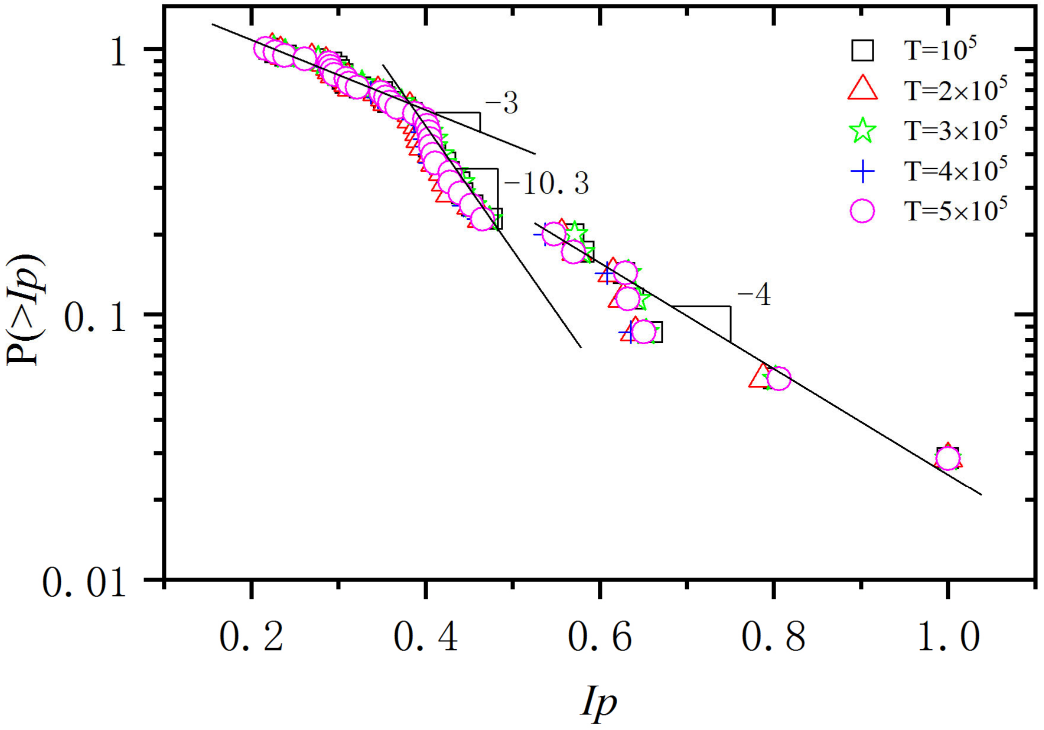

Fig. 5 Cumulative investment probability distributions for different values of $T$ .

Figure 5 shows the cumulative investment probability distributions for different values of the maximum time steps ($T$ ). According to the Linear-Log plot, the cumulative investment probability distribution basically follows an exponential distribution,

$$P(>Ip) \propto Exp\{-\delta \cdot Ip\} \tag{18}$$

where $\delta$ is the exponent. Based on the slopes of the fitted lines in Figure 5, the exponent $\delta$ satisfies,

$$\delta = \begin{cases} 3, & if\ 0.2 \le Ip \le 0.4; \\ 10.3, & if\ 0.4 \le Ip \le 0.5; \\ 4, & if\ 0.5 \le Ip \le 1. \end{cases} \tag{19}$$

According to the feature of the exponential distribution, we can obtain that the cumulative investment probability distribution decays fast. It implies that there are only a few potential ports, whose investment probabilities are relatively large. Hence, we can focus on these potential ports, which satisfy the priority conditions for port construction investment.

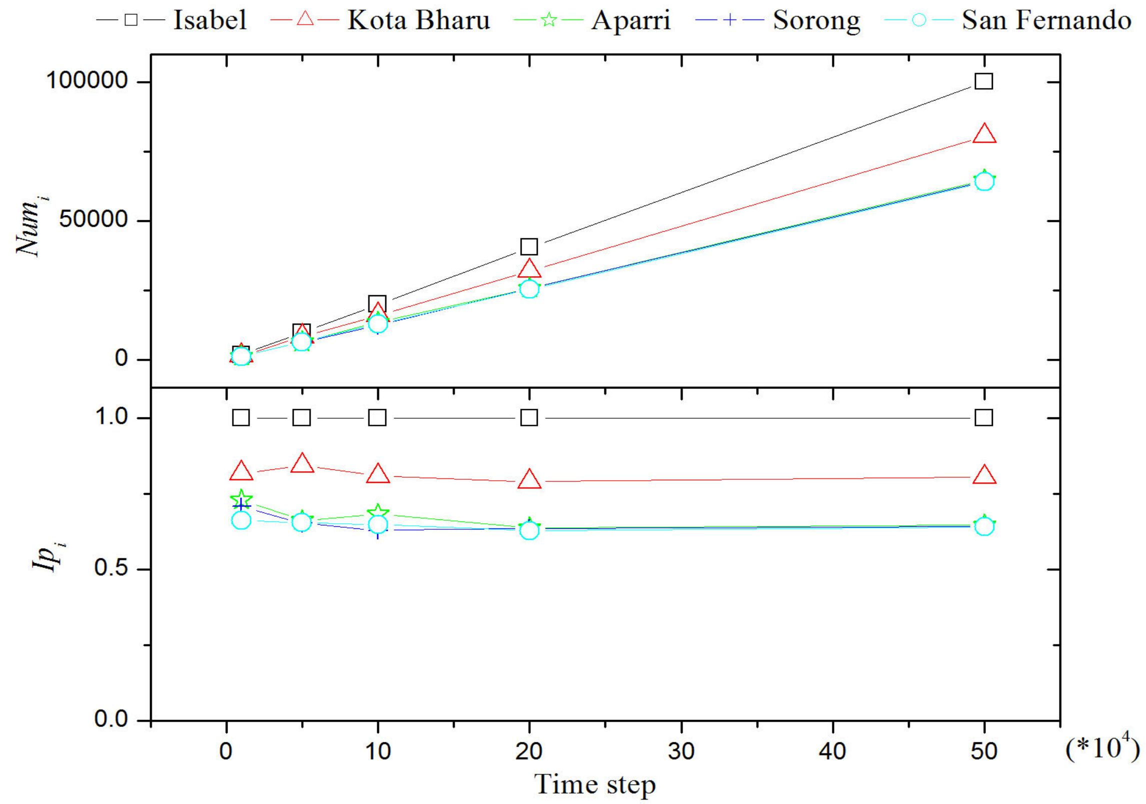

Fig. 6 The investment probabilities and the number of visited times versus different time steps for five potential ports.

Next, we verify the stability of our results on the investment probabilities of different potential ports at different time steps. Figure 6 shows the results (the investment probabilities and the number of times to be visited by all random walkers) for the top 5 potential ports (Isabel, Kota Bharu, Aparri, Sorong, and San Fernando) with respect to the investment probability. One can find that, there is a stable linear relationship between $Num_i$ ($\forall i \in P_p$) and $T$. Namely, we have

$$Num_i \propto c_i \cdot T \tag{20}$$

where $c_i$ is a coefficient associated with any potential port $i$ ($\forall i \in P_p$). In addition, we can obtain a stationary investment probability for each of these 5 potential ports when $T \geq 200000$. Hence, our results are quite stable. It is also notable that some of the Indonesia sites are close to those discussed in Tu et al. (2018).

Table 3 The top 10 potential ports with respect to the investment probability.

| No. | Port | Country | Investment probability |
|---|---|---|---|
| 1 | Isabel | Philippines | 1 |
| 2 | Kota Bharu | Malaysia | 0.78873756 |
| 3 | Aparri | Philippines | 0.629214857 |
| 4 | Sorong | Indonesia | 0.626720786 |
| 5 | San Fernando | Philippines | 0.621781549 |
| 6 | Batangas | Philippines | 0.563464313 |
| 7 | Nghe Tinh | Vietnam | 0.550211507 |
| 8 | Pemangkat | Indonesia | 0.461867619 |
| 9 | Legaspi | Philippines | 0.442966477 |
| 10 | Melaka | Malaysia | 0.444898159 |

Finally, we show the top 10 potential ports with respect to the investment probability, as shown in Table 3, where $T = 400000$ is considered. One can find that a number of potential ports in Philippines satisfy the priority conditions for port construction investment, where the Isabel port in Philippines has the largest investment probability, as compared with other considered potential ports. This is because these potential ports in Philippines are mainly located near the shortest paths of many OD pairs between China and Southeast Asia, thus benefited from both economic and geographic proximity. According to our results, we can further have the following suggestions:

(i) The national cooperation between Philippines and China has a huge development potential, and should be significantly improved in the near future. As compared with other Southeast Asian countries, the current national cooperation evaluation index of Philippines with China is relatively low.

(ii) To promote the transportation infrastructure construction along the MSR region, China has commenced the transnational port construction projects, including the Gwadar Port in Pakistan and the Piraeus Port in Greece. The Southeast Asian countries are among the most important regions along the MSR, and Philippines is strategically located in the entrance to Southeast Asia. Investing port construction in Philippines can be a good choice for China to accelerate the implementation of the MSR initiative.

## 5 Summary and discussions

This paper models the port investment priority in the Southeast Asian region, so that efficient and sustainable investments can be made under the BRI. Based on the link prediction theory, a random walk method is proposed to assess the priorities of port construction investment at different sites. The random walk method explicitly considers important economic and political factors, especially those linking the Southeast Asian countries with China (e.g., the national cooperation level of Southeast Asian countries with China). The model is calibrated and verified with numerical experiments, so that policy and managerial recommendations can be obtained for the region. Specifically, the modelling results compare the investment probabilities between the realistic ports and the potential ports in Southeast Asia. The cumulative investment probability distribution follows an exponential distribution, implying that only a few potential ports will satisfy high priorities of port construction investment. Moreover, investment probabilities at different potential ports are stable, and show that a number of potential ports in Philippines satisfy the priority conditions for port construction investment.

Our study introduces a new dimension in port investment evaluation in that the effects of shipping network are endogenously considered. Instead of analyzing individual port, our investigation is carried out for multiple sites across countries, and explicitly considers economic and political factors linking Southeast Asian countries with China. Some consistent results have also been obtained from the numerical experiments. Overall, our study offers both methodological and managerial contributions to solve important issues in the maritime industry. Still, readers should be cautioned about some limitations. For example, some parameter values used in numerical analysis are subjectively chosen based on our review of the literature. Although extensive sensitivity tests can be carried out to test their qualitative impacts to the modelling results, in practical decision-making it is good to validate the chosen values with carefully designed empirical analysis. In addition, although we have tried our best to compile official statistics from various statistics agency (e.g. GDP and GRDP), some statistics errors may still persist. Finally, individual ports may have their own characteristics in terms of service quality, efficiency, connection to shipping lines. To the best of our knowledge, few studies have formally incorporate them into *ex ante* investment modelling. It is nevertheless good to consider port characteristics in future studies. These extensions are expected to bring new insights to the literature, albeit beyond the scope of the current study.

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