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Optimal location of dry ports in the Pan-Pearl River Delta

Qitao Wu[1], Hongou Zhang[1] and Yang Wang[1]

[1] *Guangzhou Institute of Geography/Guangdong Public Laboratory of Geospatial Information Technology and Application/ Guangdong Institute of Innovation and Development, Guangzhou 510070, China*

Abstract. Dry ports have become a very important part of globalization and a cornerstone in port competitiveness. Based on the analytic hierarchy process, this paper established the dry port index system to evaluate the potential location of dry ports linked to the port system in the Pearl River Delta, in a case study covering 115 cities in the Pan-Pearl River Delta. The results show that it is optimal to locate 21 dry ports in the research region, and each dry port serves different areas. There are 4 optimal transport corridors for the dry port logistic network, including Guangzhou-Kunming transport corridor，Guangzhou-Chengdu transport corridor, Guangzhou-Changsha transport corridor and Shenzhen-Nanchang transport corridor.

1 Introduction

With continuous economic development, coastal port expansion is under growing pressure brought by traffic congestion, land constraints, environmental pollution, etc., hence coastal ports have begun to build inland dry ports. A dry port refers to an inland logistics and distribution center which is located away from and closely linked to the seaport by rail, road, or inland waterway, providing warehousing, customs clearance and other value-added services [1]. The dry port originated in Italy and then spread throughout Europe and North America [2]. It has the advantages of increasing cargo transport, reducing pollution, facilitating transport, enhancing safety and security, and lowering transport costs, and can also promote the economic development of the hinterland. In recent years, coastal ports have started to strengthen logistics cooperation and consolidation with the hinterland by locating and building dry ports there. Dry ports have become a new part of port competiveness in addition to dock facilities and shipping lines as well as a priority in the future development of ports in China and abroad [3].

In their systematic research on the dry port, overseas scholars have summarized the concept, functions, and classification of the dry port[4], analysed its advantages[5], assessed its environmental effects and impacts[6], and analysed the roles of different stakeholders in dry port construction[7]. They have also conducted case studies on numerous dry ports in different parts of the world, including West Europe and North America [3], North Europe [8], India[9-11], Malaysia[12], Russia[13], and China[14]. In China, a growing number of studies on the dry port have been conducted, but most of them are confined to the introduction of the dry port and qualitative research of its economic and social benefits [15-18]. The site selection and location of dry ports is an important aspect of dry port studies, on which domestic and foreign scholars have made many attempts with numerous methods. Studies on optimal location of dry ports mainly use two techniques. The first one is use a systematic network model and data about cargo flow between the coastal port and the hinterland to calculate the location and network structure of dry ports under the condition of minimum logistics costs; models and methods used include the hub-and-spoke network model [19], ant colony algorithm [20], mixed integer arithmetic model [9,21], and bi-level programming model[22]. The second is to establish an evaluation indicator system of dry port location, using methods such as the analytic hierarchy process (AHP)[23-24] and cluster analysis[25-26] to calculate the dry port location indicators of alternative regions for the selection and optimal location of dry ports. Both approaches have their own pros and cons: The first method features dry port location and optimization based on logistics cost control, yet it requires gaining access to complete, detailed data of cargo flow between the coastal port and all alternative dry port locations (origin-destination data), which are difficult to obtain; what’s more, such data are not completely recorded and vary from year to year, and may thus affect the simulation results. The second one is frequently adopted nowadays and easy to use, but it hardly takes into consideration actual cargo flow and transport network. Hence it is necessary to conduct an optimization analysis taking the current logistics situation into account. Meantime, how a scientifically reasonable indicator system is established also have some impact on research findings.

As the maritime Silk Road construction keeps advancing, Guangdong Province is speeding up the construction of the Pearl River Delta (PRD) as an international logistics and distribution center, actively locating and building dry ports in the Pan-Pearl River Delta (Pan-PRD) to enhance interconnection with inland regions and create smooth intermodal transport corridors. With the Pan-PRD region as the object of study, this study is intended to, by establishing an indicator system, conduct a systematic evaluation of the scientific reasonability of cities in the region as a potential dry port location, optimize the PRD port system's dry port location and transport corridor network in the Pan-PRD, with a view to providing scientific basis for dry port location and construction of the PRD port system.

2 Research methodology and region

2.1 Research region

The PRD port system, consisting of hub ports, such as Guangzhou Port and Shenzhen Port, and important ports, including the ports of Humen, Zhuhai, Zhongshan and Huizhou, is one of the top three port systems in China. Amid the trend that large-sized container vessels and international liner alliances become prevalent, PRD ports have become vital nodes of global ocean shipping, with a total of more than 320 international shipping lines and 50-plus shipping lines to Taiwan, connecting with over 200 ports in more than 100 countries and regions. In response to increasingly stiff competition in recent years, all the ports have begun to strengthen construction of inland dry ports to expand their service coverage of the hinterland. In 2014, the container throughput of the PRD port system exceeded 46 million TEUs, including 24.03 million TEUs handled by Shenzhen Port and 16.60 million TEUs handled by Guangzhou Port, and the two ports combined to account for 89% of the region's total. The ports of Shenzhen and Guangzhou, both having extensive international shipping lines and complete inland transport network, are the leading ports of external ocean shipping for the hinterland. Therefore, this paper analyzed the location of inland dry ports linked to the PRD port system with the ports of Shenzhen and Guangzhou as the key objects of study.

The Pan-PRD concept was proposed by the Guangdong provincial government in 2003, referring to a regional economic circle consisting of nine provinces and autonomous regions, namely Guangdong, Fujian, Jiangxi, Hunan, Guangxi, Hainan, Sichuan, Yunnan, and Guizhou, plus the Hong Kong and Macao special administrative regions, which is called "9+2" for short. The Pan-PRD has a land area of 1.99 million km2 and a population of 446 million, making up 20.78% and 34.76% respectively of the country's total area and population. The study focused on the location of dry ports linked to PRD ports by rail. Hainan Province is excluded from the study as it can connect with PRD ports by convenient sea transport. The Special Administrative Regions of Hong Kong and Macau are also not included in the research region due to their specialty. The real scope of the study covers eight provinces and autonomous regions in the Pan-PRD, namely the provinces of Guangdong, Fujian, Jiangxi, Hunan, Sichuan, Yunnan, Guizhou and Guangxi Zhuang Autonomous Region, consisting of 115 prefecture-level cities and autonomous prefectures.

2.2 Research methodology

The optimal location of dry ports involves many elements and decision-making comparison. This study used the AHP to explore the most optimal location. The AHP was proposed by Thomas L. Saaty in the 1970s. It models a complex multi-goal decision-making problem as a system and breaks it down into multiple goals or criteria, and then selects an optimal decision from multiple decision alternatives through quantitative analysis of qualitative indicators.

The first step was establishing an evaluation indicator system of dry port location. The site selection of the dry port as a link between the coastal port and the hinterland involves regional transport conditions and infrastructure, economic development and polity support, among other things. The study established the composite index and indicator system of dry port location mainly based on the above three elements (Table 1).

Regional transport conditions and infrastructure are important elements affecting logistics and distribution costs and efficiency. Regional transport capacity is a significant element influencing dry port logistics and distribution; the geographical advantages of regional transport determined by the conditions of transport infrastructure are major elements affecting dry port site selection. (1) The size of regional transport volume. Reflecting the demand and supply of regional transport and logistics market and the development level of the regional transport sector, it is measured by regional freight volume, consisting of rail, road and shipping freight volumes. (2) Regional transport infrastructure. It reflects the conditions of infrastructure connecting regional urban center with the surrounding areas. Good external linkage is a vital foundation for logistics and distribution. It is measured by the number of freeways, national and provincial highways, and railways in the region.

Regional economic development and foreign trade constitute an important foundation of regional external logistics and a determinant of dry port location. (1) Regional economic development has an impact on the region's output of goods suitable for container shipment and the volume of goods needed to be transported into the region for production and consumption purposes. It is measured by regional GDP, regional gross output value of industrial enterprises above designated size, and regional total investment in fixed assets. (2) Container generation and transport is an important product of external trade. Transnational corporations and investment are a driving force of the growth of foreign trade and a cornerstone of the efficient operation of dry ports. This indicator is measured by the actual utilization of foreign investment, total amount of imports, and total amount of exports.

The dry port construction must meet the requirements of national macro-economic and transport development planning. Location priority shall be given to regions with national policy support to create better external conditions for container logistics. (1) Policy conditions. The main consideration is whether the candidate city is a national comprehensive transport hub and a national road transport hub. (2) Rail transport conditions. The main consideration is whether the candidate city is a rail container handling center or a rail container handling station.

Table 1. The indicator system of dry port location.

Objective layer (weight)	Theme layer (weight)	Indicator item (weight)
Regional transport infrastructure (0.2)	Size of regional transport (0.1)	Rail freight volume (0.0249)
		Road freight volume (0.0594)
		Shipping freight volume (0.0157)
	Transport infrastructure (0.1)	Number of freeways (0.0167)
		Number of national highways (0.0167)
		Number of provincial highways (0.0167)
		Number of railways (0.050)
Regional economic development & foreign trade (0.6)	Regional economic development (0.3)	GDP (0.100)
		Gross output value of industrial enterprises above designated size (0.100)
		Total investment in fixed assets (0.100)
	Regional foreign trade (0.3)	Actual utilization of foreign investment (0.150)
		Total amount of imports (0.075)
		Total amount of exports (0.075)
Development policies & external conditions (0.2)	Policy conditions (0.1)	National comprehensive transport hub (0.075)
		National highway transport hub (0.025)
	Rail transport conditions (0.1)	Container handling centre (0.075)
		Container handling station (0.025)

Second, each of the indicators was assigned a weight by expert scoring. In this study, 43 questionnaires were sent to scholars and experts of domestic scientific research institutions and Guangdong provincial transport and port authorities for them to rate the importance of each pair of indicator items on a scale of 1 – 9, and a total of 21 validly completed questionnaires were recovered. The average values of all indicator items derived from the statistics of the questionnaires were calculated by the Data Processing System (DPS) to yield the weights of all parametric indicator items (Table 1). The DPS calculation results indicated that all the weights passed the consistence checks of single hierarchical ranking and overall hierarchical ranking.

Third, the data were normalized to be all positive. The formula of normalization is:

$$Z_i = \frac{A_i - A_{\min}}{A_{\max} - A_{\min}} \quad (1)$$

In which, Zi denotes the normalized datum, and Zi∈[0,1]; Ai denotes the actual value of the indicator; Amin denotes the minimum value of the indicator; Amax denotes the maximum value of the indicator.

Finally, the composite indexes of all cities as dry port location alternatives were calculated. The composite index represents a combination of all elements of each candidate city. The bigger the composite index of a city, the more suitable the city is to be selected as the dry port location.

The calculation formula of the composite index is:

$$C_i = \sum_{i=1}^{n} Z_i \times G_i \quad (2)$$

In which, Ci denotes the composite index of dry port location for the ith city ; Zi denotes the normalized value of the ith element; Gi denotes the weight of the ith element.

2.3 Data Sources

The data used in modeling are sourced from officially published statistical yearbooks and relevant plans. Among them, the quantitative data including regional GDP, gross output value of industrial enterprises above designated size, total investment in fixed assets, actual utilization of foreign investment, rail freight volume, highway freight volume, and shipping freight volume are sourced from China City Statistical Yearbooks, and the total amounts of imports and exports are sourced from statistical yearbooks of the relevant provinces and autonomous region. The data about freeways, national and provincial highways, and railways are sourced from the 2015 edition of China Atlas published by SinoMaps Press. Data about national comprehensive transport hubs, regional road transport hubs, container handling centers, and container handling stations are sourced from the relevant plans published on the website of the PRC Ministry of Transport.

3. Research findings

3.1 Calculation results of the composite index of dry port location

As shown by the calculation results of three indicator items, the three highest rated cities in the calculation results of regional transport infrastructure (Figure 1a) are Guangzhou, Chengdu, and Kunming. In terms of spatial distribution, the index is generally higher for provincial capitals and their surrounding areas and lower for cities far away from the provincial capital. From a regional perspective, the PDR is rated the highest, followed by the Changsha-Zhuzhou-Xiangtang (CZT) region and the region on the West Coast of the Taiwan Straits. In terms of regional development and foreign trade (Figure 1b), the calculation results of the index vary greatly, with most cities rated lower. In spatial distribution, except for the PRD, the index is generally higher for provincial capital cities and lower for other regions. As shown by the calculation results of development policies and external conditions (Figure 1c), the index is evenly distributed among all cities and generally higher for most regions, except some remote cities and regions.

Weighted summing of the calculation results of the three indicator items yielded the dry port location composite indexes of all cities (Figure 1d). The index ranges among the cities from the maximum value of 76.64 to the minimum value of 0.04, with an average of 11.77. As for the distribution of values, the index is higher for a small number of cities; only 31 cities, accounting for 26.96% of all the cities in the research region, are rated higher than the average value. With regard to spatial distribution of the composite index, for the PDR, the region on the West Coast of the Taiwan Straits, and the CZT region, cities with a higher composite index are relatively concentrated; by contrast, in Guizhou, Yunnan, Jiangxi and Guangxi, regions with a higher composite index are scattered, and there is a sound spatial combination of cities at different levels.

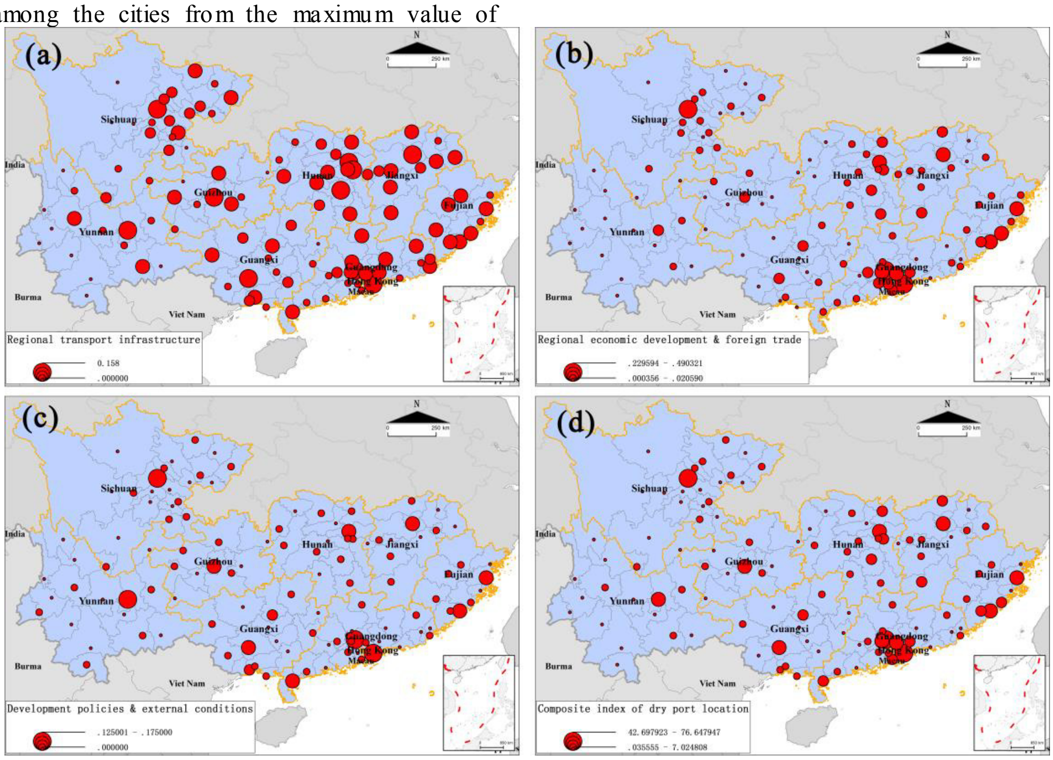

Figure 1. The computing result of (a) regional transport infrastructure, (b) regional economic development and foreign trade, (c) development policies and external conditions, (d) composite index of dry port location.

3.2 Optimal dry port location

As large-sized logistics infrastructure, a dry port mainly serves the city where it is located and the surrounding areas, hence its location shall take into account the conditions of alternative cities themselves and, more importantly, scientifically reasonable spatial distribution. The composite index of dry port location reflects the order of priority of all regions in dry port location. The higher the index of a city, the more probable it will be selected; and the lower, the less probable. However, the composite index only indicates the potential of a city being selected as the dry port location. The spatial distribution of dry ports is not necessarily dependent on the composite index. As illustrated by the spatial distribution of dry port location composite indexes of the cities, cities with a higher index are largely distributed in eastern regions and relatively concentrated. If the number and location of dry ports completely depend on the composite index ranking, it will result in imbalance among the regions and duplicated construction. Optimal dry port allocation requires optimal selection based on considering spatial distribution. Each province shall be considered separately with service coverage divided spatially. On the assumption that each province is allocated with three dry ports and considering that coastal prefectures and cities already have ports, coastal cities in Guangdong, Guangxi, and Fujian are excluded from being an alternative dry port location. The optimal allocation in the Pan-PRD of dry ports linked to the PRD port system was yielded according to the composite indexes of dry port allocation of alternative cities in the provinces and autonomous regions.

It is optimal to locate 21 dry ports in the Pan-PRD (Figure 2), among which, 3 ones are located in Chengdu, Dazhou, and Neijiang of Sichuan Province; 3 ones are located in Kunming, Dali, and Honghe of Yunnan Province; 3 are located in Guiyang, Zunyi and Liupanshui of Guizhou Province; 3 ones are located in Nanning, Liuzhou, and Guilin of Guangxi Zhuang Autonomous Region; 3 ones are located in Changsha, Hengyang and Yueyang of Hunan Province; 3 ones are located in Nanchang, Jingjiang and Ganzhou of Jiangxi Province; 3 ones are located in Zhaoqing, Shaoguan and Meizhou of Guangdong Province. Each of these dry ports serves different parts of the province. Let's take Guizhou Province for example. The dry port in Guiyang mainly serves central and southeast Guaizhou, the one in Zhunyi serves north Guizhou, and the one in Liupangshui serves west Guizhou, south Sichuan, and northeast Yunnan.

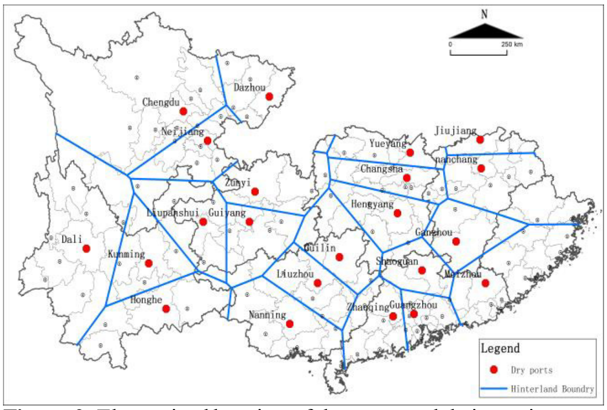

Figure 2. The optimal location of dry ports and their service coverage.

3.3 Optimal transport corridor of dry ports

Dry ports are linked to PRD ports mainly by existing trunk railways, optional depending on distance. All dry ports are connected with PRD ports by rail. From a dry port, containers are transported by rail to PRD ports or inland regions. In the selection of regions to be served by a dry port, the surrounding areas of the dry port are selected as its service area due to their closest proximity. The optimization yielded four transport corridors between dry ports and PRD ports (Figure 3), with all inland dry ports located on the four axial transport corridors.

The Guangzhou-Kunming transport corridor runs from Guangzhou through Zhaoqing and Nanning to Kunming, and can further extend to the prefectures of Dali and Honghe. Linking a total of five cities where dry ports are located, the transport corridor is underpinned by the Nanning-Kunming, Litang-Zhanjiang, Guangzhou-Maomin railways, and in the future transport distance and time through the transport corridor will be further shortened with the construction and operation of the Luoding-Cenxi railway. The corridor is mainly used for container transport between Guangzhou Port and south Guangxi and Yunnan, with a huge potential for development. Its construction has now taken shape. Guangzhou Port has built its "Dry Port in Kunming", shortening the time of container transport between Kunming and Guangzhou Port form 7 days to 54 hours, and realizing one-stop customs clearance in Kunming for local goods. The Guangzhou-Chengdu transport corridor runs from Guangzhou through Zhaoqing, Liuzhou, Guiyang, and Chongqing to Chengdu, also extending to the two dry ports in Panzhihua and Guilin. This corridor involves a total of nine cities where dry ports are located, and among all the corridors, it has the most extensive service scope and links the largest number of cities. This corridor is underpinned by the Chengdu-Chongqing, Chongqing-Guizhou, Guizhou-Guangxi, Jiaozuo-Liuzhou, Guangzhou-Maoming railways, and with the construction and operation of the Liuzhou-Zhaoqing railway in the future, the container transport distance and time through it will be reduced to save costs. Mainly serving north Guangxi, Guizhou, Sichuan, and possibly Chongqing, it is the most important corridor for PRD ports to expand their service scope to southwest China. The corridor is very long with a huge service space, covering many economically developed cities in the region, and therefore has the biggest potential for value growth. The Guangzhou-Changsha transport corridor runs from Guangzhou through Shaoguan and Hengyang to Changsha, and can extend to Yueyang, with the expansion potential for connection with Hubei Province. It runs through four cities where dry ports are located, mainly serving the markets of north Guagndong and Hunan, and is a vital container transport corridor which can indirectly serve central China and even north China. This corridor mainly relies on Beijing-Guangzhou railway for container transport. The Beijing-Guangzhou passenger rail line has been built along this corridor, greatly enhancing its cargo transport capacity, hence the regions along this corridor are key destinations for PRD ports to expand into inland container transport markets. So far the Guagnzhou-Changsha container regular train has been in operation along this corridor. Shenzhen-Nanchang transport corridor runs from Shenzhen through Ganzhou to Nanchang, and can extend to Jiuiang and Meizhou. This corridor involves four cities where dry ports are located and mainly serve Jiangxi Province, indirectly serving Anhui and even north China. It mainly relies on the Beijing-Kowloon railway for container transport and can serve the areas along the railway.

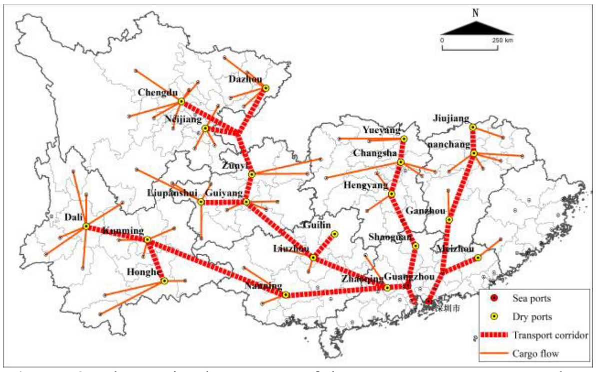

Figure 3. The optimal structure of dry port transport network

4. Conclusion and discussion

As an inland cargo distribution point linked to the coastal port, the dry port is a vital node of the linkage between the coastal port and the hinterland. The dry port construction will increase the coastal port's freight volume, expand its service coverage of the hinterland, facilitate and ease outward cargo flow from the hinterland, and therefore represents an important development direction for the construction and expansion of port service networks at home and abroad. As a case study on the PRD port system, this paper used the AHP to establish a composite indicator system of dry port location and calculate the composite indexes of dry port location for cities in the Pan-PRD region, and then conducted an optimization analysis of dry port location and transport network based on the calculation results.

(1) As shown by the calculation results of the composite index of dry port location, in the PRD region, the region on the West Coast of the Taiwan Straits, and the CZT region, cities with a higher composite index are relatively concentrated, while in Sichuan, Guizhou, Yunnan, Jiangxi and Guangxi, cities with a higher composite index are scattered, and there is a sound spatial combination of cities at different levels.

(2) According to the dry port composite index, it is optimal to locate 21 dry ports throughout the Pan-PRD region, in capital cities such as Kunming, Chengdu, Guiyang, Changsha, Fuzhou and Nanning, as well as economically developed and strategically situated cities like Guilin, Chenzhou, Hengyang, and Shaoguan.

(3) In line with the location of dry ports, it is advisable to build four transport corridors for dry ports, namely Guangzhou-Kunming transport corridor, Guangzhou-Chengdu transport corridor, Guangzhou-Changsha transport corridor, and Shenzhen-Nanchang transport corridor. Each of the transport corridors can use existing rail networks to connect different dry ports, forming an intermodal transport corridor between the PRD port system and inland dry ports.

The location and construction of dry ports is a systems engineering project, which requires taking into account numerous issues and elements including the economy, environment, investment and industry. The composite index and indicator system of dry port location reflects the reasonability of the location of dry ports in Pan-PRD cities. To build dry ports in Pan-PRD provinces and cities requires systematic planning. In particular, given that the dry port construction needs huge investments, it is necessary for dry ports located in the Pan-PRD to be constructed by phases. In the phase-by-phase construction, all the cities' composite indexes of dry port location shall be taken into consideration. Priority may be given to cities with a higher index, while cities with a lower index can wait until conditions are mature. The dry port construction also needs active cooperation from inland cities. Therefore, to achieve an optimal dry port location requires the PRD port system to, in view of the proactivity and support policy framework of inland cities for dry port construction, cooperate with inland cities to build dry ports in flexible and diverse modes of dry port construction, in a bid to advance, accelerate and improve the location and construction of dry ports. Members of the PRD port system can also team up to build inland dry ports shared by them, thereby reducing the costs of inland dry port construction. Bold attempts shall be made to pilot application of favorable policies in the PRD region to inland dry ports to help them open wider to the outside world and enable the PRD and Pan-PRD to play a still greater role in China's "One Belt and One Road" campaign.

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