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Egor PLOTNIKOV
Dalian University of Technology
Liaoning, 116023, China
Aleksandr RAKHMANGULOV*
Nosov Magnitogorsk State Technical University
Lenin av. 38, Magnitogorsk, Chelyabinsk region, 455000, Russia
**Corresponding author*. E-mail: ran@magtu.ru

MODELING CHINA'S DRY PORT COOPERATION IN SUPPLY CHAINS

Summary. Currently, focus on dry ports in the People's Republic of China (PRC) is growing, and therefore, the number of dry ports in the country is actively increasing. Due to the multifunctionality of dry ports, they meet the modern requirements of China's transport policy, which prioritizes improving the quality of providing transportation services by providing general access to value-added and high-quality services. The purpose of the PRC's transport system is also to facilitate the movement of freight flows within the State's territory, due to a faster modal shift, increased accessibility of transport, development of auxiliary functions, and construction of integrated transport hubs. Dry ports deal with the mentioned tasks; however, with the increase in the number of dry ports in the PRC, the issue of optimizing the interaction between dry ports has become urgent. The purpose of this research is to scientifically substantiate the need for strengthening technological cooperation between dry ports. The problem of determining the optimal structure of the system of interaction of dry ports was solved using the method of discrete-event simulation and the anyLogistix software tool. The results of assessment of the economic efficiency of the interaction between dry ports are presented. The results of experiments with a model of China's dry port system showed the possibility of increasing the total profit of participants of the supply chain by 2.3 times and their profitability by 2.6 times, reducing the cost of container transportation by 1.3 times, and fully meeting the demand for transportation. It has been proven that the cooperation of dry ports in supply chains provides enhanced opportunities for processing cargo flows, as a result of the redirection of cargo consignments from overloaded dry ports to dry ports with reserves with processing capacity. A methodology for optimizing the structure of the system of interaction of dry ports is presented. The methodology is proposed for use as a tool for strategic and current planning of supply chains.

1. INTRODUCTION

The current development stage of the logistics services market is characterized by intensive containerization and a rapid increase in export and import cargo flows in international traffic [1, 2]. There is an intensive growth in sea freight traffic on the China – Western Europe direction [3], which is interconnected with the period of active economic growth in the PRC. Research [4] highlights possible protracted industrialization of China, which could last until 2030, which in turn will lead to the active growth of freight traffic. The study also mentions the possibility of doubling of China's cargo turnover by 2030 (compared to 2017). Due to the multiple benefits of containers, container shipping is by far the most efficient and common way of transporting goods between the countries of the European Union (EU) and the PRC [5]. Fig. 1 shows the dynamics of the volume of international maritime trade by type of cargo. This figure shows the growth index of transport volumes compared to the base year 1990, which also confirms the active containerization of freight traffic in the international transport system.

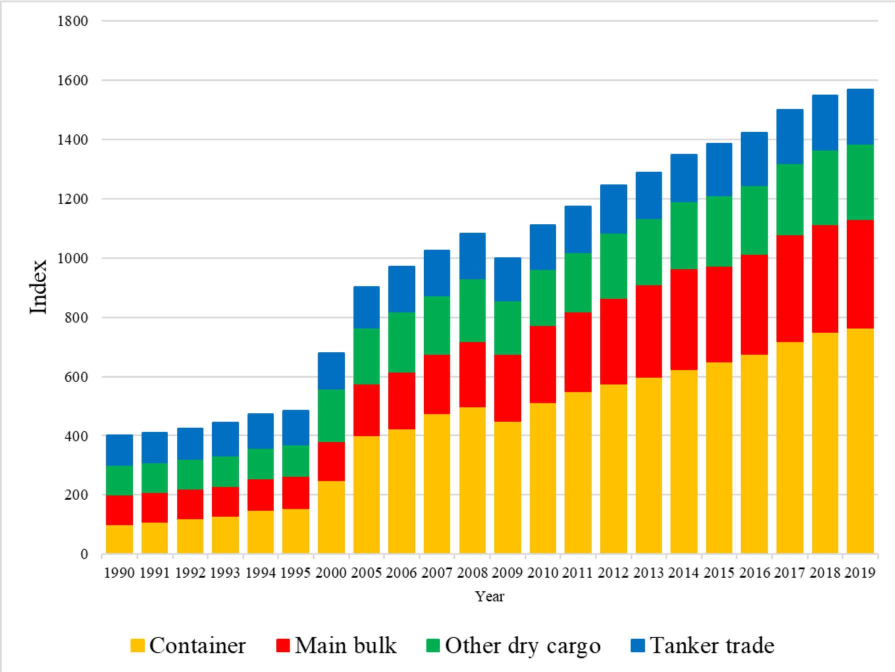

Fig. 1. Development of international maritime trade by cargo type [6]

According to statistics published by Eurostat, the specific share of China's exports to the EU reached 20% in 2017 [7]. Thus, the PRC has taken a leading position among the importers of European countries. China's export cargo flows are mainly processed in large seaports, which have the status of top-priority transport hubs [8]. However, at present, seaports more often face the problem of uneven loading, as a result of which all participants in the supply chain suffer significant losses. Basically, the uneven loading of seaports is manifested in their high congestion [9, 10]. As a result, the time spent by containers on the territory of ports increases. Delays in container processing ultimately negatively affect the competitiveness of seaports in general [11, 12]. In addition, at present, the problem of traffic jams at the entrances and exits of seaports is increasing [13]. A detailed analysis of this problem has shown that about 65% of shipping delays are due to congestion at ports [14]. A study [15] reported that there are long queues of rolling stock due to the continuous increase in container traffic and the increase in the intensity of the workload of seaports. A study [16], the aim of which was the optimization of container terminal layouts in the seaport of Montreal, analyzed the use of trucks as multimodal transport, which is also widespread in China. The authors of the research concluded that the use of trucks can increase congestion and reduce terminal capacity.

Another major problem of seaports is the accumulation of empty containers. According to a study [17], about 20% of the total number of containers transported by sea is empty. Thus, in some seaports, a problem of accumulation of excess empty containers could arise, which will obstruct their operation, while in other seaports, a shortage of containers for loading could arise [18]. This will lead to an imbalance between exported and imported containers, which will also result in an increase in the cost of shipping.

In 2020, due to the imbalance in container traffic between the US, EU, and the PRC, there was an increase in the cost of the maritime component in transportation. The lack of containers and shipping capacity has had a significant impact on the increase in freight costs. According to the Shanghai Containerized Freight Index, which is shown in Figure 2, the weighted average sea freight at the end of 2020 almost tripled compared to the same indicator in 2019. The increase in the cost of freight in the future will reduce the demand for sea freight, which, in the long term, will entail significant losses in the operation of the seaports of China.

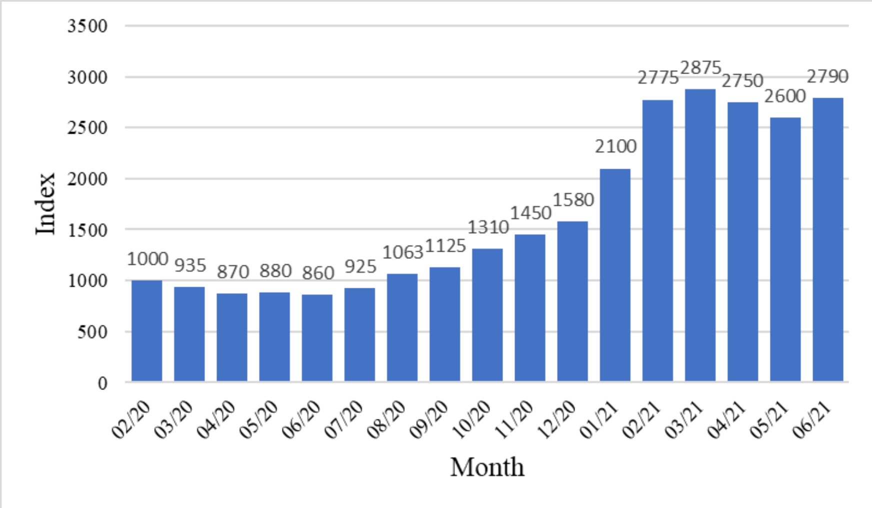

Fig. 2. Shanghai Containerized Freight Index [19]

In addition, the operation of seaports depends on many internal and external factors and is also accompanied by many different risks [20]. The problem of the materialization of risks, as well as their negative consequences, has been well studied by modern researchers. The reasons for the marked increase in the volume of freight traffic are natural risks (abnormal weather conditions, outbreak of infectious diseases), political risks (political instability, military conflicts, terrorism), and economic risks (economic crisis, growing competition), which lead to an increase in the unevenness of freight traffic and, as a consequence, may cause delays or disruptions in the operation of seaports [21-24], and also results in a negative impact on the operation of all links in the supply chain [25].

Due to the issues outlined above, the attention of a wide range of specialists in the transport industry is focused on solving the problem of lack of handling and processing capacities of seaports [26, 27].

Based on international experience, increased flexibility in managing the parameters of a seaport [28] can be achieved through interaction with inland container terminals called dry ports [29] and delegating to them part of the seaports' functions [30] for further promotion of cargo flows and the smooth functioning of large seaports. According to a study [31], a significant increase in the throughput and processing capacity of the seaport by 25-30% is possible due to the construction of a dry port. Dry ports also facilitate the efficient distribution of container flows within and outside seaports [32], improve seaport–hinterland proximity, enhance seaport capacity, and accelerate the volume of container flows [33]. Dry ports are also an effective solution to the problem of uneven cargo flows because of the accumulation of ship lots and their delivery to seaports as needed [3]. In addition, dry ports have several advantages that can improve the quality of logistics services, for example, increasing the competitiveness of logistics operators by reducing the time of cargo transportation [34]. Multitasking and efficiency of dry ports are highly valued by all participants in transport activities, including investors [35] and public authorities [36]. In this respect, a growing enthusiasm for the concept of a dry port can be seen nowadays. Therefore, there is active development of and an increase in the number of dry ports all over the world [37].

The study of the dry port concept has yielded several directions that are guiding further development. The most common studies analyze the problem of choosing the optimal geographic location of dry ports [38-43], the problem of the correlation between seaports and dry ports [11], the cost–benefit evaluation of dry ports [44-46], the impact of dry ports on the ecological condition of the regions [47, 48], etc. However, it should be noted that most of the recent studies consider dry ports within a specific supply chain. At the same time, the number of dry ports around the world continues to grow.

Recently, studies have focused on various aspects of competition [49] and cooperation between seaports [50]. However, the authors were not able to find a systematic study of the effectiveness of the systemic interaction of dry ports. Considering the significant number of dry ports and container terminals in the territory of the PRC, which often also operate in coordination with seaports, the dry ports and seaports of the PRC were selected as the subject of this study. The main goal of this study is to scientifically substantiate the effectiveness of strengthening systemic interaction between dry ports in supply chains.

The rest of the paper is organized as follows. Section 2 provides justification for the choice of a method, a research tool, and a plan of experiments with a model of a system of dry ports. The description of the model and the results of the experiments with the developed model are presented in Section 3. Section 4 presents a discussion of the results obtained. The conclusion presents a brief description of the results obtained, recommendations, and the authors' vision of directions for further development of this study.

2. METHODOLOGY

Since the operation of seaports involves many different risks, their occurrence critically affects the operation of seaports and leads to significant financial losses for all participants in the supply chain. The negative consequences of the onset of risks are manifested in the uneven loading of seaports, which leads to long delays and disruptions in their work. The most relevant examples of risk materialization are the COVID-19 pandemic [51], the 2018 financial crisis, trade sanctions and restrictions. For example, the blockage of the Suez Canal by one of the largest container ships in the world, Ever Given, led to the largest congestion, resulting in a delay in the transport of cargo of $ 9.6 billion a day between Asia and Europe [52].

The adverse impact of risks exacerbates the increase in the unevenness of cargo flows in seaports. This study hypothesizes that the redistribution of cargo flows between dry ports is an effective way to ensure uniform loading of seaports. Moreover, the organization of systemic interaction of dry ports will help to improve the overall performance of supply chains, which include dry ports.

The authors chose a set of dry and seaports as the subject of this study. The efficiency of transformation of the set of dry ports into a system is investigated. The elements of the dry port system are suppliers generating cargo flows, dry ports, and transit seaports, as well as seaports located in the territory of consumption of freight flows. This system includes the existence of links between suppliers, dry ports, and seaports, links between exporting and consuming seaports, and also considers possible links between dry ports.

The authors chose simulation modeling as a research method. The simulation model allows the study of various options for the structure of the system of dry ports and considers the influence of various factors on the performance of this system. The discrete-event approach was used to build the simulation model, which was implemented in the anyLogistix supply chain modeling program. This software combines analytical optimization methods and simulation modeling, and based on the specified parameters and limitations, it optimizes the supply chain. In addition, anyLogistix includes a regularly updated database of actual data on transport communications and other objects of transport and logistics infrastructure.

Profit, traffic volume, cost of transportation, the coefficient of variation of traffic flows, and level of meeting the demand for transportation were used as parameters and indicators of the studied supply chains and the system of dry ports. The structural elements of the study were the number of dry ports and the number of connections formed between ports in the system. Thus, the chosen method made it possible to study the operation of dry ports in the system, to provide an economic assessment of the effectiveness of technological cooperation between dry ports and its impact in improving the efficiency of the goods movement process as a result of the combined use of the capabilities of individual dry ports and the redistribution of the workload between them in the case of congestion of individual elements of this system, and changes in the parameters of production and consumption.

The experiment plan includes the following steps:

1. Choosing a basic supply chain scheme. This study examines a linear supply chain diagram (supplier - dry port - seaport - consumer).
2. Determination of the main parameters of the basic type of supply chain and its simulation model development.
3. Analysis and evaluation of indicators of the basic type of supply chain.
4. Experimenting with supply chain options to determine the number and list of dry ports to meet the required supply chain capacity.
5. Checking the possibility of improving the performance of the supply chain as a result of the organization of technological interaction of dry ports.
6. Simulation of variations in cargo flows and congestion of dry ports and seaports in the supply chain and the choice of a rational type of structure of the dry ports system to ensure the specified values of the indicators of the supply chain functioning with the predicted values of the coefficient of variation.

The presented plan of experiments can be used in the future as a methodology for testing the effectiveness of supply chains of various structures.

3. DATA, EXPERIMENTS, AND RESULTS

The nodal elements of the basic supply chain include 3 supplying cities located in China, 4 consuming seaports located in the United States, 8 dry ports, and 3 seaports located in China. The main parameters of the supply chain nodes are presented in Table 1 and Table 2.

Table 1

Production level and demand for transportation

Supplier	Production, million TEU/year	Customer	Demand, million TEU/year
Harbin	5	Port of New York	7.32
Xiamen	11	Port of New Orleans	3.66
Zhangjiakou	8.12	Port of Los Angeles	10.98
-	-	Port Norfolk	2.16
Sum	24.12	Sum	24.12

Table 2

Dry ports' and seaports' capacities

Dry port	Freight turnover of dry port, million TEU/year	Seaport	Freight turnover of seaport, million TEU/year
Mudanjiang	2.4	Dalian Seaport	9.61
Shenyang	1.8	Tianjin Seaport	14.4
Zibo	1.2	Ningbo Seaport	21.6
Shijiazhuang	2.46		
Zhengzhou	7.2		
Yuyao	0.84		
Yiwu	8.22		

The basic configuration of the supply chain was as follows: there is a concentration of cargo flows in three large cities of China (Harbin, Xiamen, and Zhangjiakou). After the consolidation of cargo flows, each of the supplying cities transports the consignments in 40-foot containers to the dry ports (Shenyang, Yiwu, Zibo) and then to the corresponding seaports (Dalian, Ningbo, Tianjin). Finally, containers are transported to the major seaports of Northern America (Port of Los Angeles, Port of New Orleans, Port of Norfolk, Port of New York). Figs. 3 and 4 show a screenshot of a simulation model and a basic supply chain scheme constructed in the anyLogistix program.

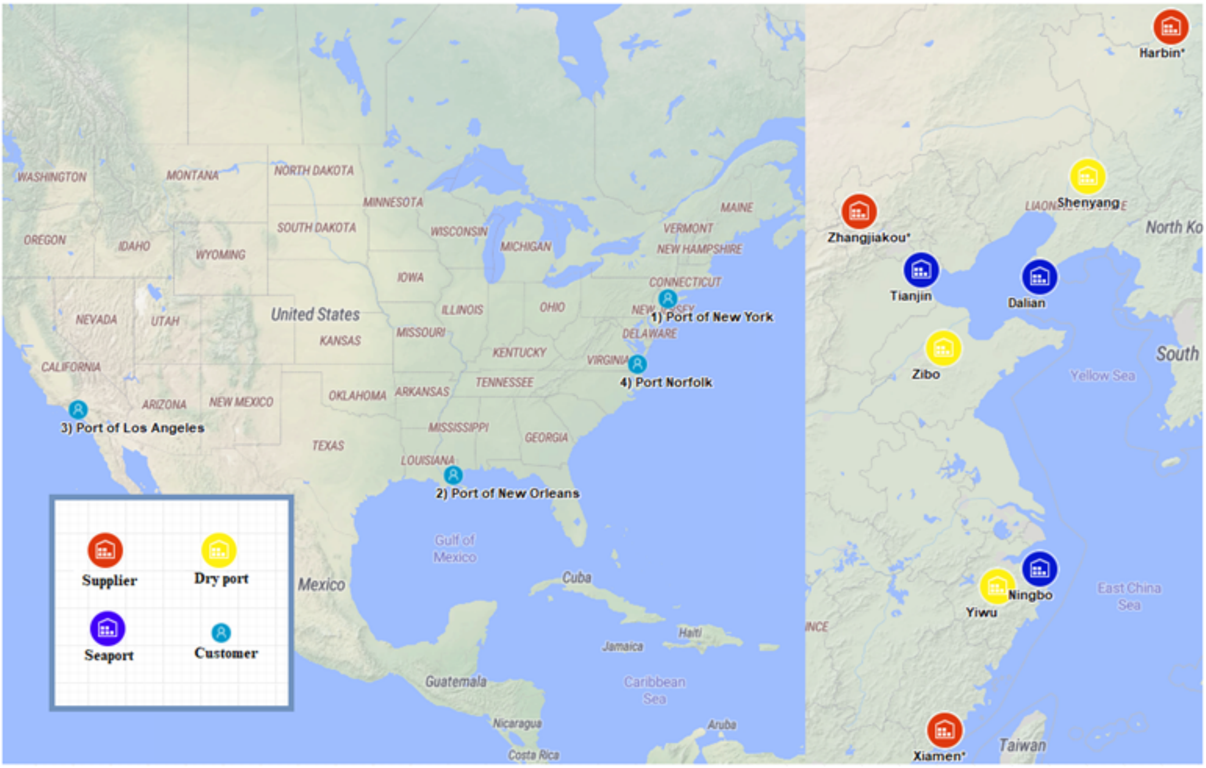

Fig. 3. View of the simulation model in anyLogistix program

Transportation simulations in the basic supply chain have shown that transportation demand is fully met only for the Port of Los Angeles. The Port of New York demand satisfaction rate does not exceed 3.3%, and the demand of the other two ports is not being satisfied (Table 3). As a result, the total loss due to unmet demand for transportation will amount to USD 49.9 billion. This is due to the fact that the dry ports in the basic type of the simulation model were not able to handle the entire incoming volume of cargo since the total throughput of the dry ports is less than the volumes of production and consumption. As a result, there is an accumulation of freight flows in these parts of the supply chain, which leads to long delays and financial losses.

To increase the total throughput of the supply chain and move the required volume of cargo, Zhengzhou dry port (Fig. 5, b), Yuyao dry port (Fig. 5, c), Shijiazhuang dry port (Fig. 5, d), and Mudanjiang dry port (Fig. 5, e) were sequentially added to the simulation model. Thus, the total throughput of dry ports in the supply chain became equal to the total demand for transportation for the seaports of North America. Table 3 shows the changes in the percentage of meeting the demand for transportation for seaports of North America for the analyzed supply chain configuration types. Even though the inclusion of auxiliary dry ports made it possible to level the total capacity of China's dry ports and the total demand for transportation (Fig. 5, e), the demand for transportation is not fully satisfied. The problem is that, along the specific part of the supply chain, the supplier sends a larger volume of cargo to the dry ports than they can handle.

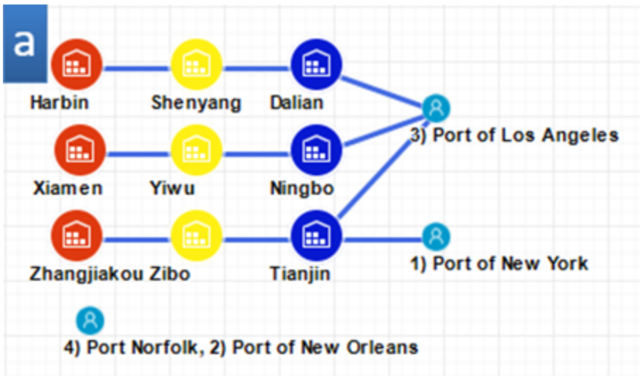

Fig. 4. Basic supply chain scheme in anyLogistix program, type «a»

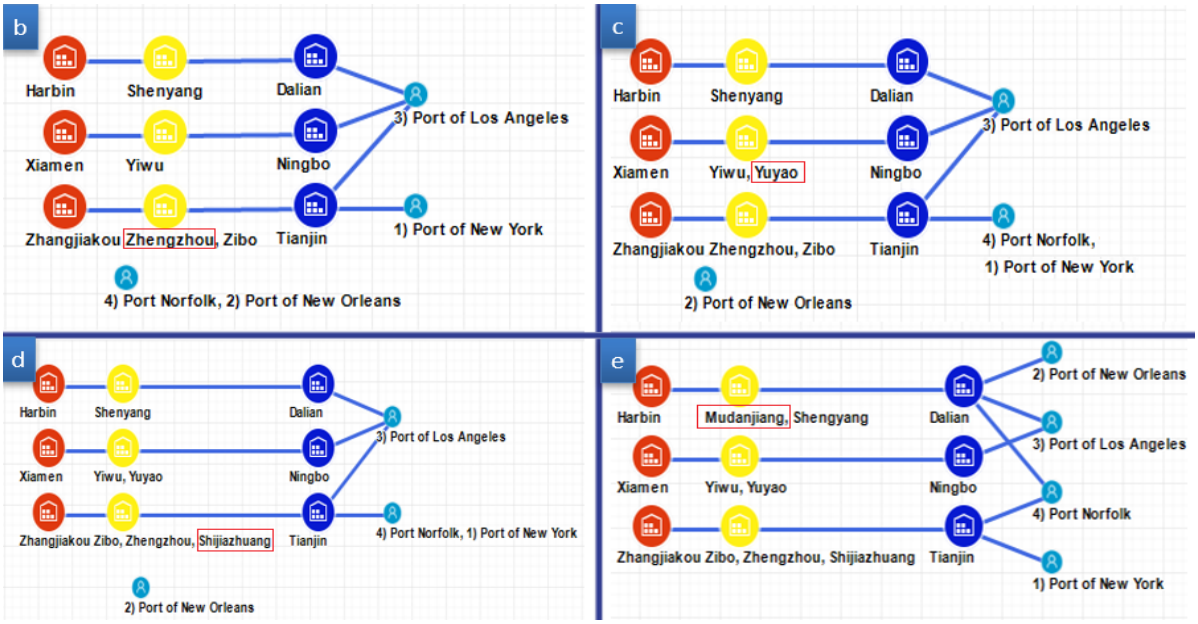

Fig. 5. Configuration types «b» - «e» of the investigated supply chain

Table 3

Percentage of meeting the demand for transportation by supply chain types

№	Customer	Demand, million TEU/year	Meet the demand, %					
			a	b	c	d	e	f
1	Port of New York	7.32	3.3	97.9	100	100	100	100
2	Port of New Orleans	3.66	0	0	0	0	25.3	100
3	Port of Los Angeles	10.98	100	100	100	100	100	100
4	Port Norfolk	2.16	0	0	31.9	31.9	100	100

To test the hypothesis about the influence of technological interaction between dry ports on the satisfaction of demand for transportation and other indicators of the supply chain, all possible transport links between suppliers, consumers, and dry ports are added to the scheme of the studied supply chain (Fig. 6). It is assumed that in case there is no reserve capacity for any of the dry ports, the model will redirect the traffic through the dry port, which currently has the necessary reserve. The presence of such links in the model mimics the technological interaction of dry ports in the supply chain.

With the expansion of opportunities for the redistribution and promotion of freight flows in the system of dry ports, there is an intensive growth in the total profit throughout the supply chain. Moreover, the transition from the non-systemic functioning of dry ports (Fig. 5, e) to systemic cooperation (Fig. 6) is characterized by an increase in the total profit along the supply chain from $ 12.1 billion to $ 28.2 billion, i.e., by 2.3 times. Figure 7 shows the relationship between the profit and the configuration of the supply chain.

In the developed simulation model, all processes associated with the operation of dry ports were deterministic. The flows in such a system were pre-distributed among all elements of the supply chain. This distribution does not prove the existence of systemic interaction between the operating dry ports, since the model does not consider such stochastic parameters as uneven supply and demand, the variability of cargo flows, the presence of failures in the operation of dry ports, and overloading of some of them. The system is characterized by the strength of the connections between its elements. The system of dry ports is determined by the ability to coordinate and adjust the routes of cargo flows movement when changing the processing capacity of individual dry ports as well as changing the intensity of cargo flows. To create a more realistic model of the system of dry ports, stochastic parameters such as uneven production and consumption volumes, and variability of the reserves of the processing capacities of dry ports and seaports were considered.

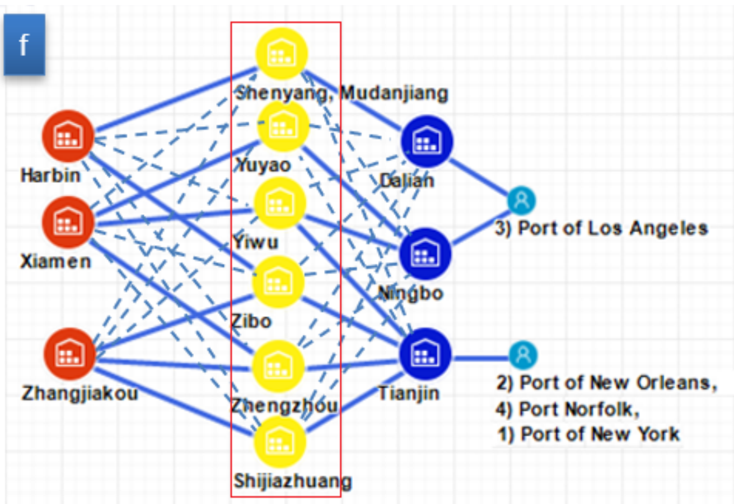

Fig. 6. Supply chain configuration when organizing a dry port system, type «f»

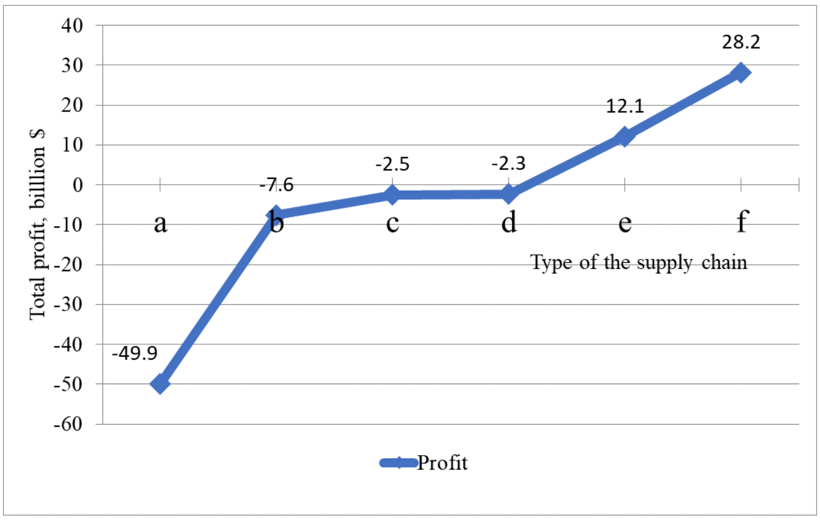

Fig. 7. Relationship between the profit and the type of supply chain

Provided that the coefficient of variation of freight traffic changes from 0 to 0.7, the results of experiments with the model for type «f» of the supply chain showed that already at a value of the coefficient of variation of 0.2, the percentage of demand satisfaction decreases to 83.25% (Fig. 9), and a decrease in profit to zero occurs when the coefficient of variation increases to 0.42.

To reduce the impact of unevenness on the functioning of the supply chain, an additional Anyang dry port was added to the simulation model. The throughput of this dry port is 2.4 million TEU / year. The supply chain configuration for type «g» is shown in Fig. 8.

Figures 9 and 10, respectively, show curves of the traffic demand satisfaction and total supply chain margins. Each of the graphs has two curves: the blue curve shows the dependence of the indicators of the system of dry ports on the coefficient of variation of container flow before the inclusion of Anyang dry port in the supply chain (types «a» - «f») and the orange curve shows the results after adding Anyang dry port (type «g»).

From the above graphs, it can be clearly seen that the curves reflecting the estimated performance after adding the auxiliary Anyang dry port to the system are located above the curves of customer satisfaction and the total profit in a balanced supply chain. Due to the systemic interaction of the elements of the supply chain, it became possible to change the routes of transportation and distribute freight flows between cooperating dry ports in a timely and effective manner, which had a positive effect on the economic efficiency throughout the supply chain. Thus, it was confirmed that there are sufficiently strong links between the elements of the dry port system, which shows higher economic indicators. Table 4 presents the main indicators of the studied supply chain types.

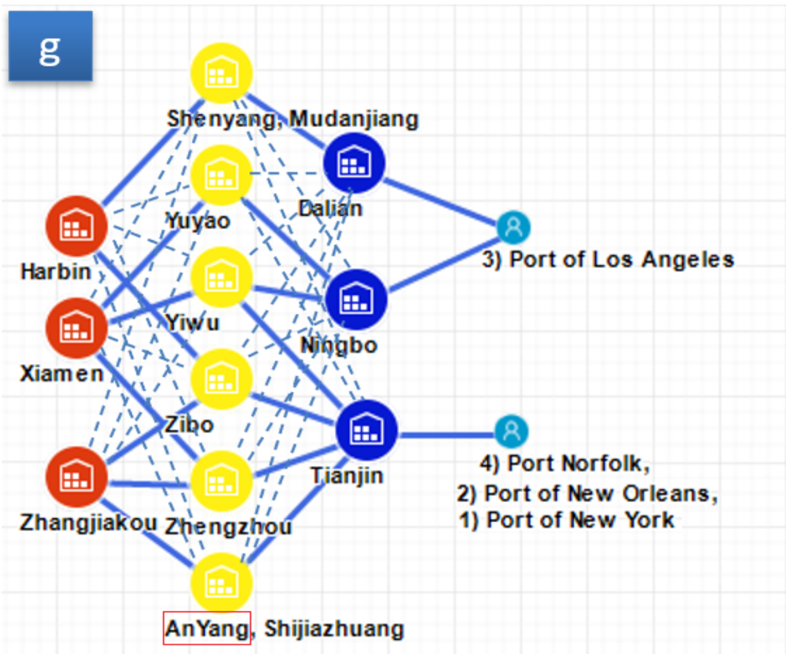

Fig. 8. View of the updated supply chain after the addition of Anyang dry port, type «g»

4. DISCUSSION

The analysis of the results obtained showed that the supply chain schemes in which technological cooperation of dry ports is organized demonstrate higher operation indicators. In this study, the efficiency of the system was assessed by the cost of transportation of goods and the profitability of transportation. A gradual decrease in the prime cost and an increase in the profitability of transportation were observed both as the number of dry ports in the system increased and as a result of the organization of technological links between them. The results of the experiments carried out using the model of China's dry port system demonstrated the complete meeting of the demand for transportation and showed the possibility of increasing the total profit by 2.3 times (from $ 12.1 billion to $ 28.2 billion), increasing the profitability of transportation by 2.6 times (from 19.1% to 50.1%), and reducing the transportation cost by 1.3 times (from 733.5 $/container to 582.6 $/container). Based on the results of the experiments, the authors assume that the organization of technological linkages and the strengthening of the interaction between the existing dry ports of the PRC will contribute to a more intensive realization of the economic, social, and environmental potential of dry ports, and an increase in total profit will have a beneficial effect on all participants in the supply chain.

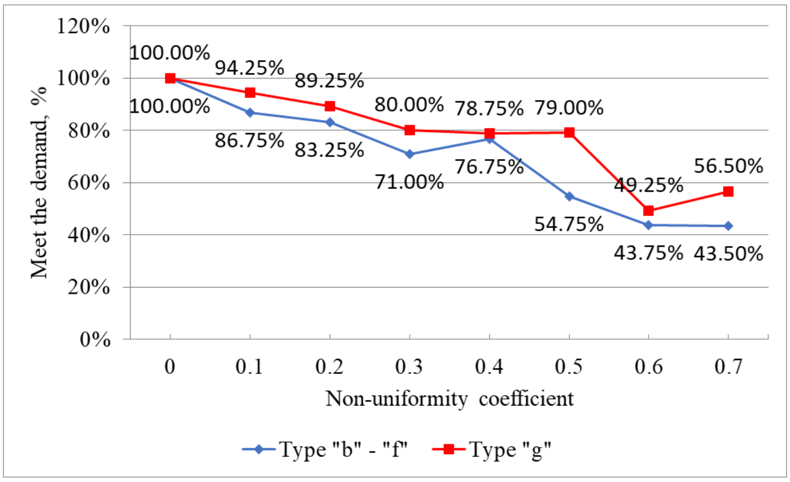

Fig. 9. Relationship between meeting the demand for transportation and the coefficient of variation of freight traffic

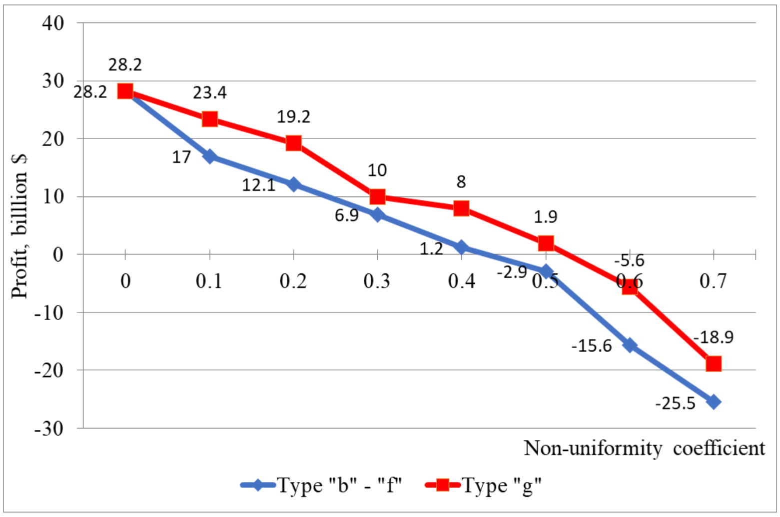

Fig. 10. Relationship between the profit of the supply chain and the coefficient of variation of freight traffic

Table 4 presents the results of experiments with models of various configuration types of the supply chain. Optimization of the connection scheme (type «a») and addition of dry ports to it (types «b» - «e») were carried out at 0 value of the coefficient of variation. In experiments for configurations «f» and «g», the coefficient of variation varied from 0 to 0.7. The presented results show the influence of the number and total capacity of dry ports (types «a» - «e») as well as the presence of technological links between the elements of transport and logistics infrastructure (types «f» and «g») on the efficiency of the supply chain.

Therefore, the problem of too weak or absent links between the existing dry ports of China was solved by developing a simulation model and conducting optimization and variation experiments using the model. The results of the experiments proved that the cooperation of dry ports in the supply chain provides enhanced opportunities for processing cargo flows, increasing the overall throughput of the supply chain. Experiments with the simulation model of the system of dry ports confirm the hypothesis about the possibility of reducing container delays in port terminals in such a system and overcoming the large financial losses connected to them in the supply chains. In addition, the main advantages of the dry port system are as follows:

- reducing the unevenness of cargo flows; reducing the load on seaports and adjacent territories; and increasing the throughput and processing capacity of seaports,
- increasing the efficiency and quality of the goods movement process as a result of achieving a synergistic effect and flexible redistribution of freight flows,
- creating conditions for the adaptation of transport systems to changes in international trade,
- increasing the socio-economic level of development of hinterlands and regions where infrastructure elements of supply chains are located,
- reducing the cost and time of delivery and storage of goods, and
- decreasing the harmful impact of transport on the environment.

Table 4

Technical and economic indicators of the researchable model of China's dry ports system

Configuration of the supply chain	Number of dry ports	Capacity, million TEU/year	Coefficient of variation	Profit, billion $	Total cost, billion $	Freight turnover, million t-km	Transportation cost $ /TEU	Profitability of transportation, %
a	3	11.22	0	-49.9	89.1	44.9	1984.4	-50
b	4	18.42	0	-7.6	71.1	72.6	979.3	-10
c	5	19.26	0	-2.5	68.9	75.9	907.7	-3
d	6	21.72	0	-2.3	68.7	75.9	905.1	-3
e	7	24.12	0	12.1	62.7	85.5	733.5	19.1
f	7	24.12	0	28.209	56.191	96.5	582.6	50.1
			0.1	17	63.9	92.5	690.8	26.6
			0.2	12.1	59.9	82.2	728.7	20.2
			0.3	6.9	66.9	84.3	793.5	10.3
			0.4	1.2	72.2	83.9	860.5	1.6
			0.5	-2.9	80.4	88.6	907.4	-3.6
			0.6	-15.6	92.7	88.1	1052.2	-16.8
			0.7	-25.5	103.5	89.2	1160.3	-24.6
g	8	26.52	0	28.291	56.109	96.5	581.8	50.3
			0.1	23.4	58	93.1	622.9	40.3
			0.2	19.2	61.3	92	666.3	31.3
			0.3	10	59.2	79	749.3	16.8
			0.4	8	67.9	86.8	781.3	11.7
			0.5	1.9	70	82.2	851.5	2.7
			0.6	-5.6	93.6	100	936	-5.9
			0.7	-18.9	78.6	68.2	1152.4	-23.9

The limitations of the system of dry ports include the need to solve organizational problems of interaction and finding a balance between the effectiveness of competition and cooperation between dry ports [53]. In addition, the differences in the levels of economic development of the regions where dry ports are located should be considered, as well as the management models used in the PRC based on close monitoring of the central government and provincial and municipal governments [54].

Thus, for the effective functioning of dry ports, which continue to increase, in the territory of the PRC, the authors propose the creation and development of a single system of dry ports. However, the effective functioning of such a system is possible only after solving some technological, economic, and organizational problems. The integration of separately functioning dry ports of the PRC into an effective system is the solution to the above problems, which will also contribute toward sustainable development of regional economies and increase the level of socio-economic development of the regions where dry ports are located.

5. CONCLUSIONS

Analysis of the practice of functioning of dry ports located in PRC, as elements of transport and logistics infrastructure and supply chains, revealed several shortcomings of the existing theoretical developments and the practice of their implementation. The need to strengthen technological cooperation between dry ports in supply chains is a major challenge as their number grows.

Evaluation of the effectiveness of the organization of technological interaction of dry ports was carried out using simulation modeling of various types for supply chain schemes with the participation of dry ports. The variants of the schemes differed in the number of dry ports in the system and the possibility of redistributing cargo flows between them. Experiments with the supply chain model were carried out at different values of the coefficient of variation of freight traffic (from 0 to 0.7). When choosing a variant of the structure of the system of dry ports, the authors strove to overcome the financial losses related to delays and accumulation of containers in dry ports and seaports.

It is shown that as a result of the organization of the opportunity to redistribute uneven cargo flows from overloaded dry ports to less loaded ones, there is a decrease in the cost price and an increase in the profitability of transportation in the supply chain by an average of 56.5 percent. In addition, the percentage of meeting the demand for transportation increases by an average of 8.6 percent.

The presented methodology for conducting experiments with the supply chain can be used to select the optimal structure of the supply chain and justify the need to organize technological interaction between dry ports or container terminals. The authors plan to develop the proposed approach of organizing cooperation between dry ports and the methodology for optimizing the structure of the system of their interaction by considering various risk factors arising in the process of functioning of supply chains.

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