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The Introduction to System Dynamics Approach to Operational Efficiency and Sustainability of Dry Port's Main Parameters

Dmitri Muravev ^{1,2,*} , Aleksandr Rakhmangulov ² , Hao Hu ¹ and Hengshuo Zhou ³

¹ Department of Transportation Engineering, School of Naval Architecture, Ocean and Civil Engineering and State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai 200240, China; hhu@sjtu.edu.cn

² Department of Logistics and Transportation Systems Management, Mining Engineering and Transport Institute, Nosov Magnitogorsk State Technical University, Magnitogorsk 455000, Russia; ran@magtu.ru

³ Sino-US Global Logistics Institute, Shanghai Jiao Tong University, Shanghai 200030, China; 13956851083@sjtu.edu.cn

* Correspondence: Dmitri_Muravev@sjtu.edu.cn; Tel.: +86-186-2110-2872

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Abstract: The continuous increase of trade between China and Europe brought congestion problems at major Chinese seaports. An effective way to solve this issue is to set up intermodal terminals often called dry ports. However, the dynamics of various influenced factors on dry port's implementation calls for the adaptive and flexible planning of the terminal. This paper analyzes the shortcomings of previous research related to the dry port's implementation from the perspective of the applied numerous parameters concerning evaluating its operational efficiency and sustainability. The operational efficiency and sustainability of a dry port are evaluated by the developed system of the main parameters. This system gives the understanding of how these parameters are interrelated between each other and fills the gap in studies of inverse interrelations between main parameters of a dry port. To fully understand the sustainability of the main parameters of a dry port, this paper puts forward the simulation models description of the developed system. The developed model is a practical tool to evaluate the reliability of hypotheses about the functional interrelations between the main parameters of the dry port, as well as to evaluate the sustainability of the system. Finally, in order to develop functional interrelations between main parameters, the data from several Chinese dry ports has been collected. Finally, the developed multi-agent system dynamics model has been validated in the case study of Yiwu dry port located in Zhejiang, China.

Keywords: seaport; dry port; parameters; system dynamics; intermodal transportation; interrelations; terminal planning; sustainability of a dry port; simulation modeling

1. Introduction

Nowadays, the value of imported goods to the European Union (EU) has reached 5218.6 billion US dollars in 2016 or one-third of the total volume of the world import market. Furthermore, the export volume of China to the EU has doubled and equals 436.83 billion US dollars that are about 20% of the total volume of EU import market in 2017 [1]. Undoubtedly, the importance of the China-EU import markets requires the improvement of transport and logistics infrastructure. It could potentially improve handling of freight traffic flows in the East-West direction.

Currently, the most perspective direction of developing the transport links between Europe and Asia is the ancient silk route that revolutionized into the New Economic Silk Belt. This route links China overland to Europe, through Central and Western Asia and was established in the framework of

One Belt One Road Initiative [2]. Nowadays, freight traffic flows are mostly transporting between Asia and Europe through the Suez Canal, and it takes 95% of the total share between different shipping modes [3]. However, it takes more than 30 days to deliver the cargo from China to European cities by maritime transportation.

One of the main reasons for such long delivery is the congestion problem at the major seaports of China. For example, Shanghai Yangshan terminal, Qingdao and Ningbo ports are now experiencing lengthy delays and vessel queues at anchorage waiting to enter terminals by at least two days, over 80 units of vessels waiting outside Shanghai [4]. According to comments from the Maersk shipping line, the leading causes of congestions are long stays of containers at the terminal and challenging weather conditions in China [5]. Another reason for such an extreme situation at Chinese seaports is the limited throughput and storage capacities. Drewry company mentioned that the ports faced the worst of the congestion registered and the biggest container volume growth in the first quarter of 2017: Qingdao (12%), Shanghai (10%) and Ningbo (9%). It means that possibilities to improve the throughput in major seaports of China are limited [5].

Since the port congestion problem becomes important, the Ministry of Transport of the People's Republic of China has been paying significant attention to the development of port infrastructure. They have issued several plans in 2015, such as "Construction Scheme of Freight Hub and scheme for the Collection and Distribution System for the Ports during the 13th Five-Year Plan (from 2016 and 2020)" [6]. Mainly, these hubs aim to solve congestion problems and improve the performance of major seaports to attract the containerized cargoes, which are also called dry ports [7]. The dry port concept is based on a seaport directly connected with inland intermodal terminals where goods in intermodal loading units can be turned in as if directly to the seaport [8].

However, the frequent changes in the schedules of ships and truck arrival times due to increased traffic volume, customs clearance, and other disruptions, such as breakdowns of equipment and bad weather conditions, contribute to the dynamics. It means that dry ports have been adapting the challenges in operations, such as difficulty in meeting different stakeholder objectives, capacity constraints, limited availability of transportation modes and location at non-strategic areas [9]. This complexity and dynamics call for adaptive and flexible planning in intermodal terminals [10]. Consequently, the crucial terminal management problem is to predict optimal physical and technical parameters of intermodal terminals, parameters of traffic flows that represent high investments and characterized by social, economic and environmental impacts [11]. The wrong prediction of these parameters would hamper the long-term operation of dry ports and increase their operating costs.

Undoubtedly, numerous studies have been devoted to the numerous factors affecting the location of transport and logistics facilities. In other words, these studies are associated with facility location problem (FLP). One of the well-known methods to solve this problem is fuzzy multicriteria decision making method since distribution networks are usually in uncertain environments [12]. Ou and Chou applied weighted fuzzy factor rating system in FLP, which is based on assigning the individual fuzzy weight to respond individual decision makers empiricist or expertise with an open and judgmental group decision-making procedure [13]. Li et al. [14] proposed fuzzy topsis method based on entropy weight that was applied to select the location of the logistics center in China. This method attempts to choose alternatives that simultaneously have the shortest distance from the positive ideal solution and the farthest distance from the negative-ideal solution. However, all attribute values must be numeric, monotonically increasing or decreasing, and have commensurable units that could potentially sophisticate the data collection. The Vikor method developed by a Serbian researcher Opricovic [15] has been successfully applied in FLP [16,17]. It is based on conflicting and non-commensurable (attributes with different units) criteria, assuming that compromise can be acceptable for conflict resolution, and when the decision-maker wants a solution that is the closest to the ideal solution, the alternatives can be evaluated according to all established criteria. These two presented methods have several disadvantages, such as correlations between criteria, uncertainty in obtaining the weights only by objective methods or subjective methods and the possibility of alternative close to the ideal point

and nadir point concurrently [18]. Collectively, these methods have several limitations, such as most of the experts' evaluation based on their personal opinions, sensitivity to inconsistent data, difficulties in development, can require numerous simulations before method's application.

The contribution of this paper is twofold. Firstly, this work includes a thorough literature review on various parameters aimed at solving different issues of the dry port implementation. Secondly, this work presents the developed system of the main parameters of a dry port. This system focuses on the evaluation of the operational efficiency of an intermodal terminal. Then, it gives the understanding of how this system of the main parameters of the dry port could be applied to the stage of strategic planning. It is crucial to evaluate the reserves of a dry port regarding increased volumes of freight traffic flows. Furthermore, this paper presents the mathematical model of the dynamic sustainability of the main parameters of the dry port, obtaining the optimal coefficients of linear functional interrelations between each other. Moreover, the case study on the main parameters of a dry port is presented. Finally, the paper provides a possible application of the system dynamics approach for predicting the values of the main parameters characterized by reduced costs. Specifically, this issue refers to different classes of stakeholders and decision makers, such as port authorities and government.

The rest of the paper is organized as follows. Section two outlines the relevant literature. The third section develops the system of main parameters of a dry port that could be potentially applied in the strategic planning stage and mathematical model of dynamic sustainability of the main parameters of the dry port. The fourth section presents a case study on the main parameters of the dry port. Finally, this paper summarizes future development strategies of dry ports.

2. Literature Review

Many efforts have been devoted to the research on the inland intermodal terminals. Slack mentioned that freight terminals have four principal functions: transfer of cargo, mostly unitized, between two modes, the assembly of freight in preparation for its transfer, the storage of cargo awaiting pick-up, delivery and the logistical control of flows [19]. Furthermore, except these four functions, services, such as maintenance of containers, customs clearance, and other value-added services should be taken into account at a dry port terminal. Moreover, he pointed out that the implementation of satellite facilities/terminals for container storage could relieve congestion at the marine terminal [19]. Woxenius et al. stated that the modal shift from road to rail resulted in reduced congestion at the seaport gates and its surroundings, one train can substitute more than 100 in the US, and reduce external effects along the route, such as emissions, noise, road accidents [20]. Van Klink and van den Berg mentioned that inland terminals could potentially enlarge the hinterland of the seaport. Since the role of ports has changed into the node of logistics chains [21], they are more active in extending their intermodal terminals [22,23]. Besides the key benefit of physical expansion of a seaport and solving the issues of limited throughput capacity [24], inland terminals could solve other issues rising in intermodal transportation. Crainic suggested applying a dry port as a way to solve scheduling problems in freight rail transportation [25]. Henttu noted that dry ports' implementation is a way to solve environmental problems of the area of a seaport's location [26]. Monious pointed out that dry ports could potentially improve the social and economic indicators of a region where intermodal terminals would be located [27].

One of the most important questions at the dry port planning is where to allocate an intermodal terminal and how to make it with minimum investment costs. This question is associated with container terminal planning. Sun et al. mentioned that operators of busy container terminals need to periodically evaluate options for capacity expansion to meet the increasing demands for container handling at their terminals [28]. Roy mentioned that due to significant investments involved in the development of a container terminal, an optimal design of the terminal is crucial [29]. Hence, the critical task for designers is to gain in-depth knowledge of the site, and its current physical, geographical and environmental characteristics [30]. Another task is to find optimal storage capacity and throughput capacity for processing raised traffic volumes.

Since a dry port consists of many elements, such as specific use terminals, depot, repair, loading and unloading customs, we may also call an intermodal terminal a complex system. The parameters of the elements are affected by different external factors. We propose to divide external factors into infrastructure, economic, and environmental factors.

Woxenius [31] pointed out that social and economic factors should be considered. He mentioned that regions with positive population dynamics have an advantage of selecting the dry port's location in terms of the predicted demand for transport and logistics services, which potentially increases the cargo volume by intermodal transportation. Roso [32], after her interview with a dry port manager in Enfield (Australia), suggested considering the infrastructure factors, such as the effect of special time windows provided by rail operators, which destabilize the share for rail in moving the container to/from port botany and insufficient subsidies for rail from the government. Jeevan et al. [33] referred to different factors affecting the operation of dry ports in Malaysia, such as the possibility to use existing railway network instead of constructing a new private rail-haul, attraction of public-private partnership in construction of intermodal terminals, the presence of highly qualified professional workforce, allowing to provide on-time handling operations. Everett and Robinson [34] proposed to consider the local governments in port cities of Australia, which have a significant impact on the physical expansion and the level of handling equipment in freight terminals. Panova and Korovyakovsky [12] pointed out that increased foreign trade and the lack of availability to expand physically marine terminals strongly affected the increase in container stacks in the major Russian seaports. Moreover, they mentioned that the high price of land close to seaport distances the dry port's location. Finally, they studied the case of Ust-Luga dry port whose location was limited by existing nature reserves and wildlife sanctuaries.

Moreover, the environmental effect was considered, since residents faced congestion from generated road traffic as well as from rail. Henttu proved that the external costs of a dry port, including CO₂ emissions, congestion, noise, and accidents, affect the location of the dry port network in general. The conducted review shows that mainly researchers studied the impact of external factors on individual parameters of dry ports or a small group of parameters. The problem of the group of factors affecting the group of parameters has not yet been studied efficiently.

Flow of goods and vehicles are one of the key elements of the external environment in freight terminals since it directly affects continuous handling operations at dry ports. It means that the characteristics of traffic flow, such as its intensity or irregularity, directly depend on the operation of the intermodal terminal. Moreover, it hugely impacts the efficiency and equivalence of using all technical elements at a dry port. Crainic et al. [35] studied the impact of interval arrivals of rail shuttle on the technical equipment status and storage capacity at the intermodal terminal. Authors pointed out that decreased arrival intervals are required to increase the number of handling equipment and storage capacity. Rodrigue and Notteboom [36] suggested considering the effect of double-stack platforms containing up to 500 TEU of the storage capacity of the dry port.

Besides the impact of the intensity of traffic flow, its irregularity can destabilize the operation of the dry port. Brooks et al. [37] mentioned that if traffic congestion at the gates of a port with the average utilization of handling equipment passes the 70% mark, it could be managed by appropriate port capacity. Jurjevic [38] pointed out that the irregularity of vessels arrival and vehicles could be reduced by the effective organization of port operations and high-level handling equipment.

Semenov [39] mentioned that the intensity of traffic flow is not a stationary value and can vary due to various reasons, such as the impact of environmental factors (hydrometeorological factors), and denominated periodicity, in particular, seasonality. Kuznetsov et al. [40] revealed the influence of the variability of hydrometeorological conditions on designing handling equipment and storage capacity of container terminals. The incorrect evaluation of their impact leads to a change in the total project cost of the terminal to 30–40 %. Sun et al. [41] mentioned climatic conditions (heavy rain, typhoon, wind, waves) and distance of transport mode that have a significant impact on the irregularity of rail transportation between a seaport and a dry port. Moreover, Scherbakova-Slusarenko [42] proved

that irregular import and export of containers from/to intermodal terminal leads to an excess or deficit of cargo units at the container yards.

The selection of the optimal dry port's location is inextricably linked with the problem to determine the distance between existing seaport and planning terminal, as well as the capacity of transport communications. Haigermoser et al. [43] mentioned that the extension of rail distance increases the irregularities associated with repair and maintenance of railway tracks. Moreover, application of double-stack platforms reduces the speed of freight train from 110 km to 75 km [44], which affects the distant dry port [8]. Viktor noticed that the long distance between a seaport and a dry port could potentially produce emergencies on railway, such as coming off trains with environmentally hazardous types of cargo [45]. Consequently, the long distance between a seaport and an intermodal terminal increases the risks of rail disasters. It leads to the delays of vehicle and handling equipment and increases appropriate irregularity of freight traffic flows.

An increase in the distance between a seaport and a dry port requires the improvement of transport communications to further provide on-time deliveries. Bergqvist [46] studied the throughput of transport communications between the Gothenburg seaport and the Skaraborg dry port. He mentioned that train shuttle service can be cost efficient on short distances, e.g., 135 km, and with relatively small amounts of goods, as long as the timetable is set in an optimized manner. Roso [47] revealed that the extension of rail sidings at Falköping dry port increased the number of rail shuttles to four units.

Besides the evaluation of the rail distance and throughput of transport communications, the problem to find the most feasible site from the perspective of grading costs becomes increasingly important. Basically, when the port managers decided to construct a dry port, they ask design engineers to analyze the issues regarding the geography of the area and topography of the site. Valentine [48] pointed out that complex topographical conditions affect the railways in Djibouti. There are 79 curves with a radius smaller than 200 meters which seriously limits the carrying capacity of the trains operating at the port of Djibouti. Zimmer [49] proved that the high steering gradient has a negative impact on the intensity of rail freight traffic.

In order to meet the raised traffic flows and provide on-time service, intermodal terminals are required to have appropriate storage capacity and high-tech handling equipment. Jeevan et al. [9] mentioned that dry ports should be developed with adequate space so as to allow efficient, reliable and economical movement of containers, in particular when they are developed to support seaport operations. Rodrigue and Notteboom [36] pointed out that since dry port projects became increasingly capital intensive because of increased traffic at seaports, their size, required equipment and infrastructure are under risk.

However, the required level of storage capacity and handling equipment harmfully impacts the environment in the region of dry port's location. Primary sources of environmental pollution at marine terminals are dust, dredging disposal, garbage, and noise [50]. For example, the increased number of handling equipment increases the level of noise pollution [51]. Roso [47] studied the evaluation of environmental impact of Borås dry port and mentioned that CO₂ emission from the trucks during queuing at the terminals or very low-speed driving is approximately 6 kg/hour. Nguyen [52] considered noise influence from dry port activities to select the optimal location of the intermodal terminal in Vietnam. Nevertheless, it requires an increase in investment costs for purchasing environmentally friendly equipment, it would be much better to select a distant dry port [53].

One of the main performance measures of the dry port's operation is the minimum of general and operating costs [53]. Panova et al. [54] revealed taking into account general costs, such as the construction of a container yard, service buildings, motorway, and railway tracks, a transformer substation, a water supply system, gantry cranes' installation. Moreover, she proposed to consider operating costs associated with the downtime of railcars waiting for loading and unloading operations, non-productive container downtime, the cost of all-day vehicle downtime due to busy loading areas at the terminal, trains mileage, and the maintenance of rail tracks. Henttu and Hilmola [55] considered the pricing of external costs, such as CO₂ emissions, accidents, noise, and congestion which affect the

modal choice in implementing dry ports in Finland. Vehicle delays should be taken into account since they affect the operating costs of intermodal terminal and seaport–dry port as a whole. Jeevan et al. [33] interviewed seaport authorities which mentioned that inappropriate planning of container staking on the train from dry ports can cause delays in container movement and can affect the schedule integrity of vessels.

The literature review shows that theoretical and practical studies in the field of intermodal terminals have made a significant contribution to the development of dry ports all over the world. Numerous researchers have focused on various parameters for solving different issues related to the dry port's implementation. However, most of the studies related to the main parameters of the dry port are characterized by insufficient systematization. It means that scholars focus on a separate parameter or study the mutual influence of several external factors on a limited number of parameters of a dry port.

The static view of the limited number of parameters of a dry port does not allow to consider complex interactions in dynamics and makes it impossible to find the optimal combination of the parameters' values. The result of such a non-systematic approach can be represented as an increase in total logistics costs, which are one of the main issues influencing operational efficiency and sustainability of dry ports [56]. Consequently, in order to increase the operational efficiency of a dry port and minimize the total costs, it is essential to consider its parameters systematically and study their interrelations in dynamics.

To sum it up, so far researchers in the field of intermodal transportation have studied only the impact of individual parameters or factors on the efficiency of the dry port operation, or mutual influence of no more than two factors. Mainly, studies present direct relations between parameters. For example, how the intensity of traffic volume affects the storage capacity of the dry port or how the distance between a seaport and a dry port could impact the irregularity of traffic volume.

However, to the best of our knowledge, there are no studies in inverse interrelations between these parameters, i.e., how the environmental factor could influence the intensity of traffic volumes or what is the interrelation between irregular traffic and distance between two terminals.

Therefore, we aim to present an approach to systemizing parameters that have a significant impact on issues related to the dry port's construction and efficiency of its operation.

3. Sustainability of the Main Parameters of a Dry Port

3.1. The System of the Main Parameters of a Dry Port

The systematization of the main parameters of a dry port is based on a study of their mutual influence. It also has two stages, firstly, principal qualitative interrelations between selected main parameters are determined. Secondly, functional dependencies between the main parameters of a dry port are defined.

In order to study the interrelations between the main parameters of a dry port systematically, the authors propose the following main parameters of a dry port characterized by most of the investment and operating costs. These parameters were selected through surveys conducted with dry port managers from Yiwu intermodal terminal, China, Horgos Gateways, Kazakhstan, Sushary–Logistica Terminal, Russia and presented in Figure 1.

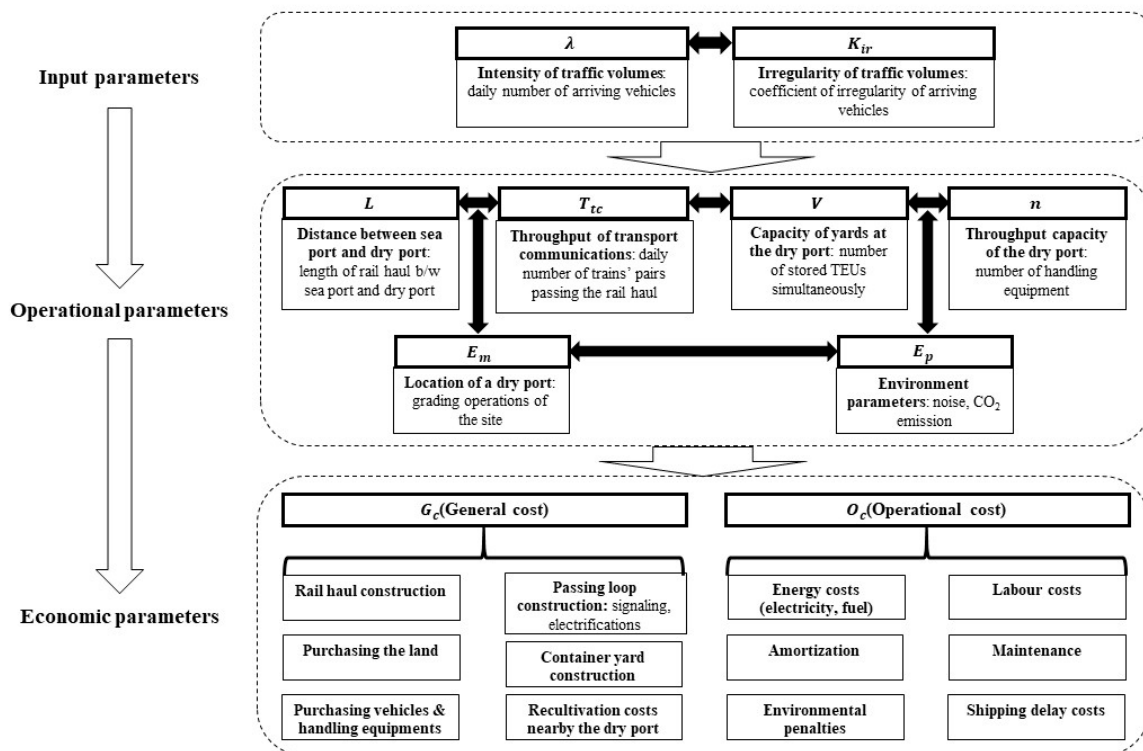


Figure 1. Main parameters of a dry port.

The main parameters of a dry port are interrelated with each other and form the system presented in Table 1. Table 1 gives an understanding of how these parameters affect each other. The next step of a study on the system of main parameters of a dry port is based on determining the functional relations between these parameters. Since specific conditions in potential areas of dry port's location could have a significant difference, for qualitative description of interrelations between main parameters, the authors propose to apply linear functions.

3.2. Dynamic Sustainability of the Main Parameters of a Dry Port

The approach to qualitatively describe the interrelations between the main parameters of a dry port by application of the linear functions has two significant advantages. Firstly, linear functions are universal and describe the principal tendency of changing one parameter when another is also changed. Secondly, this approach predicts the dynamics of these parameters with sufficient accuracy when central decisions are making on the stage of strategic planning of a dry port.

The main reason for applied linear functions is that the combination of simple interrelations between parameters of the system generates the complex network with a direct and inverse effect on each other that creates the nonlinearity and emphasizes the complexity of the system of the main parameters of the dry port [57].

To sum it up, the container terminals are complex systems, since a large number of factors affect the different parameters of container terminals.

The mathematical model of the main parameters of a dry port has two purposes. Firstly, it helps to evaluate the correctness of the system of the main parameters of a dry port. Secondly, the developed mathematical model is going to be applied as a basis for designing the agent-based simulation model.

Let us denote the presented parameters of a dry port as x_i , where $i = 1, \dots, N$ is a conditional sequential number of the parameter, $N = 10$ is a total number of selected main parameters of a dry port. We assume that the value of the parameters is some stock x_i . Then, change in stock dynamics is represented as an equation of interrelation between stocks (F) with two different directions – input

flow (I) and output flow (O). The interrelations between the main parameters in the dynamic system are presented in Figure 2.

$$\frac{dx_i}{dt} = FI_i - FO_i, \quad i = 1, \dots, N, \quad (1)$$

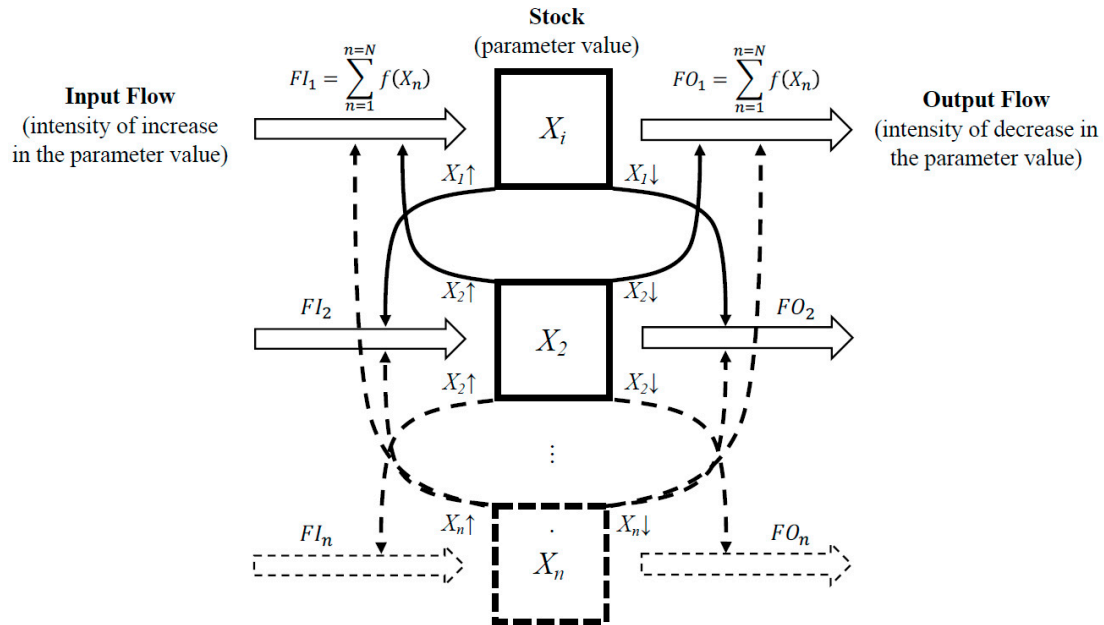


Figure 2. The scheme of interrelations between parameters in the dynamic system.

Despite the direction of the flow, its intensity is described by the following equation:

$$F_i = \sum_{j=1}^{j=N} \frac{f(x_j)}{T}, \quad (2)$$

where $f(x_j)$ is the functional linear interrelation between parameters x_i and x_j , T is the estimated period (planning period), in months. Functional interrelation $f(x_j)$ between parameters x_i and x_j affect the selection of the flows (I_i or O_i). This selection is determined by the developed matrix of interrelations between the main parameters of a dry port presented in Section 3.1. These interrelations could be formalized written as,

$$FI_i = \sum_{j=1}^{j=N} \frac{s_{ij}f(x_j)}{T}, \quad \text{where } (s_{ij} > 0 \wedge x_{j,t} > x_{j,t-1}) \vee (s_{ij} > 0 \wedge x_{j,t} < x_{j,t-1}), \quad \forall i = 1, 2, \dots, N, \quad (3)$$

$$FO_i = \sum_{j=1}^{j=N} \frac{s_{ij}f(x_j)}{T}, \quad \text{where } (s_{ij} < 0 \wedge x_{j,t} < x_{j,t-1}) \vee (s_{ij} < 0 \wedge x_{j,t} > x_{j,t-1}), \quad \forall i = 1, 2, \dots, N, \quad (4)$$

where s_{ij} are the values of interrelation coefficients of parameters in a system. If the impact of the parameter j on the parameter i is positive, $s_{ij} = 1$. If the impact of the parameter j on the parameter i is negative, $s_{ij} = -1$, if $i = j$, $s_{ij} = 0$. $x_{j,t}$, $x_{j,t-1}$ are the values of the parameters in a system, respectively, in the current and in the preceding moments of the estimated period T . Formulas (3) and (4) determine the selection of flows (FI_i or FO_i), the intensity of which changes in the moment t according to function $f(x_j)$.

Furthermore, this intensity depends on increasing or reducing the values of parameters $x_{j,t}$ in comparison with $x_{j,t-1}$ and values of coefficients s_{ij} .

The main disturbing factor in the studied system is the change of intensity of input freight traffic flows, determined by the value of the coefficient of the irregularity of these flows. Consequently, in order to determine optimal values of the main parameters of the logistics centers, the system of the main parameters should achieve a dynamically sustainable state. Different factors could lead to the imbalance in the system of the main parameters of the logistics centers.

Firstly, since the proposed main parameters are interrelated between each other through linear direct and inverse interrelations, one of the disturbing factors is the incorrect selection of relation's type between a pair of parameters. Secondly, the irrational selection of the main parameters of the dry port could unbalance the system because of the inappropriate number of inverse relations between parameters. Hence, it poses a barrier to develop the self-regulatory system of the main parameters of the dry port. Finally, the imbalance in the system may give rise because of the lack of the calibrated coefficients of the linear functional interrelations between the main parameters of the dry port.

To address this issue, we need to develop the algorithm for adjusting the values of coefficients of linear functional interrelations between parameters.

This algorithm could dynamically select the optimal values of the coefficients characterized by the stability between the main parameters of the dry port. As mentioned before, we consider the linear interrelations between main parameters of the dry port skx , where $k > 0$, while coefficient $s = 1$ ($s = -1$). If the interrelation between the pair of parameters x_i and x_j is direct or inverse (positive or negative) and $s = 0$, there is an equality between i and j . Hence, we have the matrix of symbols (positive or negative),

$$S = \|s_{ij}\|_{i,j=1}^N, \quad (5)$$

where $s_{ij} = 0$, while $i = 1, \dots, N$. Then, each of the input FI_i and output FO_i flows has two matrices of the coefficients, defining the right part of the Equation (1).

Precisely, we have

$$K^{(I)} = \|k_{ij}^{(I)}\| \text{ and } K^{(O)} = \|k_{ij}^{(O)}\|, \quad (6)$$

where all coefficients k_{ij} in both matrices are positive, except the diagonal, which are equal zero. The system (1) can be represented in the following way

$$\begin{aligned} \frac{dx_1(t)}{dt} &= \frac{1}{T} \left(\sum_{j=2}^N S_{1j} k_{1j}^{(I)} x_j - \sum_{j=2}^N S_{1j} k_{1j}^{(O)} x_j \right) \\ \frac{dx_2(t)}{dt} &= \frac{1}{T} \begin{pmatrix} \sum_{j=1}^N S_{2j} k_{2j}^{(I)} x_j - \sum_{j=1}^N S_{2j} k_{2j}^{(O)} x_j \\ j \neq 2 \end{pmatrix} \\ &\dots \\ \frac{dx_i(t)}{dt} &= \frac{1}{T} \begin{pmatrix} \sum_{j=1}^N S_{ij} k_{ij}^{(I)} x_j - \sum_{j=1}^N S_{ij} k_{ij}^{(O)} x_j \\ j \neq i \end{pmatrix} \\ &\dots \\ \frac{dx_n(t)}{dt} &= \frac{1}{T} \left(\sum_{j=1}^{N-1} S_{Nj} k_{Nj}^{(I)} x_j - \sum_{j=1}^{N-1} S_{Nj} k_{Nj}^{(O)} x_j \right) \end{aligned}, \quad (7)$$

Table 1. The system of the main parameters of a dry port.

[illegible]

Each of the matrices $K^{(I)}$ and $K^{(O)}$ has the calculated ranges of coefficients,

$$K_{\text{int}}^{(I)} = \|k_{i,j,\min}^{(I)} \cdots k_{i,j,\max}^{(I)}\|_{i,j=1}^N \text{ and } K_{\text{int}}^{(O)} = \|k_{i,j,\min}^{(O)} \cdots k_{i,j,\max}^{(O)}\|_{i,j=1}^N, \quad (8)$$

The developed algorithm is based on the following steps. We calculate the values of the parameters x_i during the estimated period T (planning period), where $i = 1, \dots, N$, for given the initial distribution of the main parameters of the dry port with the initially given matrices $K^{(I)}$ and $K^{(O)}$ (while the matrix S is fixed).

If all the main parameters of the dry port x_i after the estimated period T are in the calculated bounds $\|x_i^{\min} \cdots x_i^{\max}\|$, $i = 1, \dots, N$, the developed algorithm for adjusting the values of coefficients of linear functional interrelations between parameters is stopped.

If one or a few values of the parameters are out of the estimated bounds $\|x_i^{\min} \cdots x_i^{\max}\|$, $i = 1, \dots, N$, we should to change the coefficients of matrices $K^{(I)}$ and $K^{(O)}$ and select them from estimated interval matrices $K_{\text{int}}^{(I)}$ or $K_{\text{int}}^{(O)}$. This step explains the need to reduce the greatest impact of the affecting parameter on the parameter x_i , whose value is out of the bounds $\|x_i^{\min} \cdots x_i^{\max}\|$.

For example, if the parameter x_i is out of the estimated bounds during the estimated period T , we should find the element with the maximum (greatest) value in i -th row of matrices $K^{(I)}$ or $K^{(O)}$. For instance, it is j -th element, we should change him to the coefficient $k_{ij,\min}^{(I)}$ (or the next after him if $k_{ij}^{(I)} = k_{ij,\min}^{(I)}$). Doing this procedure for each parameter, whose values are out of the bounds in the estimated time, we obtain a system (2) with new coefficients of matrices $K^{(I)}$ and $K^{(O)}$.

Then, we calculate again new values of the main parameters of the dry port x_i in the estimated period T with new matrices $K^{(I)}$ and $K^{(O)}$. If the values of the main parameters of the dry port x_i are in estimated bounds, the algorithm is stopped. Otherwise, we should repeat the algorithm to adjust the values of coefficients of linear functional interrelations between the main parameters of the dry port.

Consequently, after a certain number of algorithm steps, we obtain the optimal values of the coefficients matrices $K^{(I)}$ or $K^{(O)}$, which provide sustainable state of the parameters x_i , $i = 1, \dots, N$, in the estimated period T .

One of the main distinctive features of the developed algorithm is its universality. The universality of the algorithm lies in its application to study different complicated systems, further identification of the parameters with the most destabilizing impact on the system and the final adjustment of their coefficients. Another feature of the developed algorithm is providing the temporary adaptation period to the main parameters after storing the selected coefficient of functional dependence into the linear function. This is necessary to determine the stability of the system of the main parameters of the logistics centers, which have 100 established connections between each other.

4. A Case Study on the Main Parameters of the Dry Port

4.1. Data Collection

To carry out the case study, we selected the Ningbo-Zhoushan seaport, which is one of the busiest ports in the world in terms of container traffic and an indispensable transport node in the logistics chain of the One Belt One Road Initiative. It handles about 25 mln TEU annually. The seaport contains 11 container terminals, which have the ability to handle the container vessels with container capacity of 21413 TEU. According to the UNESCAP (The United Nations Economic and Social Commission for Asia and the Pacific), the Ningbo-Zhoushan seaport operates with 10 dry ports [6].

In order to develop the linear functional interrelations, the data on the main parameters of the dry ports, operating with Ningbo-Zhoushan seaport has been collected primarily through the interview with the inland terminal manager, internal company reports and internet-based documents were combined in order to ensure validity through triangulation.

Yiwu dry port is the international intermodal terminal located in Zhejiang province and was constructed in 2013 in order to solve congestion problems in Ningbo-Zhoushan seaport. Nowadays, there are three daily trains from this terminal, which is located 185 km away from where the throughput of transport communications equals 12 pairs of trains daily. Moreover, it has two separated rail hauls for China Railway Express and Ningbo-Zhoushan terminal. The Yiwu dry port could simultaneously store 800 TEU and handle 450 TEU daily. Besides two reach stackers, 50 trucks, 25 RTG cranes operate at the terminal. Transportation between two terminals is organized by road transportation. Total investment costs of the project are about 461.35 million US dollars.

Shangrao dry port is an intermodal terminal located in Jiangxi province, serving as a key logistics construction project of Jiangxi province, a key project for Shangrao city to implement the grand customs clearance strategy, and a strategic measure for Ningbo port to build China's modern port logistics center and expand the inland business. Nowadays, there is only one daily train from this terminal which is located 533 km away from where the throughput of transport communications equals nine pairs of trains daily. The Shangrao intermodal terminal could simultaneously store 650 TEU and handle 275 TEU daily. Besides one RTG crane, five forklifts and 10 trucks operated at the terminal. Total investment costs of the project are about 14.35 million US dollars.

Yingtian dry port is located in Jiangxi province, constructed in 2009, in order to serve as not only the supporting logistics pivot point of copper disassembly and processing park but also the distribution center of import and export material flow in Yingtian and surrounding areas. Nowadays, it has also one daily train from this terminal which is located 660 km away from where the throughput of transport communications equals seven pairs of trains daily. The Yingtian dry port could store about 700 TEU and handles 270 TEU daily. Besides two reach stackers, 50 trucks, 25 RTG cranes operated at the terminal. Total investment costs of the project are about 14.92 million US dollars.

Nanchang dry port is the international intermodal terminal located in Jiangxi province and was recently constructed in 2017 in order to solve congestion problems in Ningbo-Zhoushan, Shenzhen, Xiamen seaports. Nowadays, there are three daily block trains from this terminal which is located 545 km away from where the throughput of transport communications equals eight pairs of trains daily. The Nanchang dry port could simultaneously store 1000 TEU and handle 650 TEU daily. Besides three reach stackers, 50 trucks, 30 RTG cranes operated at the terminal, transportation between two terminals is organized by road transportation. Total investment costs of the project are about 223.33 million US dollars.

Shaoxing dry port is the international intermodal terminal located in Zhejiang province and was constructed in order to promote the development of the export-oriented economy and improve the investment environment in the province. Shaoxing intermodal terminal consists of two different loading zones at Paojiang (constructed in 2002) and Keqiao (constructed in 2008). Nowadays, it has only two daily trains from the terminals which are located 185 km away from where the throughput of transport communications equals 12 pairs of trains daily. The Shaoxing dry port could simultaneously storage 7500 TEU and handles 350 TEU daily. Besides two reach stackers, 23 trucks, 12 RTG cranes operated at the terminal. Total investment costs of the project are about 150.32 million US dollars.

Jinhua dry port is the intermodal terminal located in Zhejiang province and was constructed in 2002, in order to fill the gap of no "pass-through customs" in the central and western part of Zhejiang province and nine cities in Fujian, Zhejiang, Jiangxi and Anhui provinces, which can reduce the transportation cost of shippers. It has five daily block trains from this terminal which is located 545 km away from where the throughput of transport communications equals eight pairs of trains daily. The Jinhua dry port could simultaneously storage 5000 TEU and handles 450 TEU daily. Besides three reach stackers, 50 trucks, 30 RTG cranes operated at the terminal, transportation between two terminals is organized by road transportation. Total investment costs of the project are about 223.33 million US dollars.

The review of the Chinese dry ports, operating with Ningbo-Zhoushan seaport shows that most of the intermodal terminals are distant [8]. There are several reasons for such a distant location and benefits for different stakeholders.

Firstly, the distant location of intermodal terminals lies in the high cost of land. For example, the land price close to the Ningbo city is about 1500 US dollars per m^2 , while in Los Angeles (US) it costs about 880 US dollars. Hence, port authorities aimed to find the most feasible (distant) location for intermodal terminals. However, currently, high transportation costs in the rail market negatively affect the demand of the customers. This problem becomes important in China, mainly for China Railway Express operating in view of One Belt One Road Initiative. To-date, there are over 43 rail routes between China and Europe. This situation has brought several problems in rail transportation, such as insufficient cargo supply, low load factor, low-profit-margin, and high pressure upon the government to subsidize the CRexpress occur [58].

Obviously, the feasible land cost would absorb high transportation costs in the long run. We aim to present several reasons for this situation. Firstly, since the local government of Chinese provinces is focused on partial subsidizing rail transportation, mainly in the framework of One Belt One Road Initiative and attract more customers, lower land costs could potentially absorb high transportation costs. Otherwise, port authorities and intermodal terminal managers aim to look for customers who are able to accept raised transportation costs. Secondly, as the dry port is located in the area with more favorable conditions, such as a small difference in elevation topography, the absence of problematic soils, we may conclude that general costs for dry port's construction will be lower. It brings an opportunity to expand the storage and throughput capacities of the intermodal terminal to handle raised traffic because one train can substitute 50 lorries. Undoubtedly, the Chinese dry ports need sustainable development with the consolidation of small traffic flows [59].

Secondly, these terminals aim to improve trade attractiveness, create job opportunities in Chinese provinces and minimize environmental impact through the modal shifting from road to rail. Furthermore, the distant dry ports could potentially gain benefits for China Railway Express which is a state-owned sole proprietorship enterprise and increase the economies of scale by providing rail transportation between the intermodal terminals and the seaport. Moreover, road operators could fully concentrate on providing the fleet with short distance transportation, which undoubtedly reduces total logistics costs. Finally, distant dry ports could minimize congestion at gates of the seaport and increase the number of on-time deliveries in multimodal logistics chains. All these benefits are outlined by the Chinese government in several plans issued in 2015, such as "Construction Scheme of Freight Hub and scheme for the Collection and Distribution System for the Ports during the 13th Five-Year Plan (from 2016 and 2020)".

Undoubtedly, the distant dry ports contribute a lot into the entire logistics chain, specifically to keep inventory costs with reasonable bounds. Firstly, distant intermodal terminals could potentially increase irregular traffic flows (transport delays) caused by emergency situations on the railways. Secondly, since the dry ports are located far from marine terminals, the delivery time also increases. Consequently, it negatively affects inventory, transportation costs and the competitiveness of intermodal terminals, respectively. Moreover, the distant dry ports imply the presence of rail passing loops, which can improve the throughput capacity of transport communications. At the same time, it brings an increase in inventory costs associated with passing loop's maintenance.

From the perspective of order cycle time, the distant dry port has an ambiguous assessment. On the one hand, since this kind of terminals are aimed to develop hinterlands and improve social and economic attractiveness of the regions, they can operatively meet the demand of shippers located nearby with the required level of storage capacity. Moreover, the distant dry ports are located close to each other and form a specific network of intermodal terminals. Hence, there are not any barriers to improving shippers' demand and being profitable. On the other hand, since we consider transport delays, distant dry ports could potentially increase back order demand associated with the seaport. This fact lies in possible existing heavy weather conditions resulting in the irregularity of traffic

flows at the marine terminal. Moreover, several factors should be considered, such as the insufficient coordination level between the port railway station and special railway tracks, random nature of trains' formation at port railway stations, provision of special time windows in the seaport to supply goods from the external network.

4.2. Agent-Based Modeling of the System of the Dry Port's Main Parameters

To achieve the stable state of the main parameters of the dry ports, we propose to design a simulation model based on the combination of agent-based and system dynamics approaches in the simulation platform AnyLogic 8.3.2. The application of combined approaches has several benefits. Firstly, the system dynamics approach is applied to study the change of the main parameter of the intermodal terminals, depending on the change of other parameters. Secondly, the agent-based approach provides the scalability of the model to study the system at micro-level. Moreover, this approach is less time-consuming and makes the developed model universal. It becomes crucial if we need to increase the number of studied parameters and factors affecting them in a system. Undoubtedly, we have the alternative to design the system dynamics of the dry port's main parameters. This alternative is based on the application of differential equations' system (analytical approach) or system dynamics (simulation modeling method). However, none of them are able to scale the system that is being crucial for micro-level cases. This situation would potentially increase labor and it is a time-consuming procedure to study the parameters of dry ports.

The main singularity of the developed model is the creation of the agents' population, which represents the main parameters of the dry port with the same structure in the agent's environment. Moreover, we recommend the simplified way of agents' interaction based on transferring the messages between each other and their further processing.

The operation of the combined simulation model is based on three main stages: running simulation model, with the application of database in the external Excel-file, generation and transferring of the messages on changing the value of the agent (main parameter of a dry port), receiving and processing these messages.

The algorithm of the running simulation model lies in the creation of an agent' population by reading external Excel-file. The example of Excel-file is presented in Figure 3. Hence, each agent in the population contains the following attributes, such as name, its sequential number in the population and arrays *FI* and *FO*, calculating the intensity of input and output flows. Once the population of the agents is created and initial values received, they start to transfer the messages between each other. In other words, the algorithm of generation and transferring the messages on changing the value of the agent is running.

	A	B	D	E	B3	=Coefficients!B3*Parameters!B3		
1	name	stock	min	max		A	B	C
2	Intensity	50,00	50,00	150,00	1	Parameter	Intensity	Throughput
3	Throughput	1,00	1,00	6,00	2	Intensity		2,00
4	Capacity	200,00	200,00	800,00	3	Throughput	25,00	
5	Handling capacity	50,00	50,00	450,00	4	Capacity	37,50	1,50
6	Coefficient of variation	1,00	0,20	2,00	5	Handling capacity	50,00	0,67
7	Distance	150,00	1,00	185,00	6	Coefficient of	0,00	3,00
8	Location	1,00	1,00	10,00	7	Distance	-34,50	4,86
9	Environmental parameter	1,00	1,00	10,00	8	Location	-0,03	-0,60
10	General costs	25,63	1,00	1,00	9	Environmental	-15,00	0,60
11	Operational costs	1,00	1,00	1,00	10	General costs	0,00	-0,02
12					11	Operational co	-0,03	-0,17
13								
	Parameters	Relations	Coefficients			Parameters	Relations	

Figure 3. The example of the input data in the Excel-file.

The algorithm of generation and transferring the messages on changing the value of the agent lies in transferring the messages between agents. In order to transfer the messages, we propose to develop the agent representing the message. Consequently, if the agent changes his value, he will send

this value to the other nine agents in the population. Then, the other nine agents simultaneously will receive and process the message on the changed value.

The algorithm of receiving and processing the messages is associated with the identification of the agent who sent the message and further replacing the changed value into linear functional relation presented in the external Excel-file. Finally, since the value is replaced, mathematical formulas are automatically calculated, and updated values of agents are shared between them.

To achieve the sustainability of the system of the dry port's main parameters during the simulation period, we have developed the algorithm to adjust the values of coefficients of linear functional interrelations between the main parameters. We propose to describe it in the following manner:

- checking the values of the agents in estimated bounds;
- searching the elements, e.g., functional interrelations in the flows *FI* and *FO* with the maximum number, Figure 2, if the values of the agents are not in the estimated bounds;
- dynamic adjustment of coefficients taken from previously calculated ranges of coefficients for each agent to minimize the impact on the agent and keep the value in the estimated bounds.

The bounds of the dry port's main parameters can be justified by minimum and maximum value. For example, the rail traffic intensity has bounds [50; 150] containers/day, where the minimum value describes the minimum number of containers in a single train and maximum value lies in the expected maximum number of containers transported by rail to the dry port and taken from collected data.

An example of calculating the functional interrelations between the main parameters of a dry port is presented in Table 2.

Table 2. The example of functional interrelations between the main parameters of a dry port.

Parameter	λ	V	G_c	O_c
$y = F(x)$		$2.57x + 150$	-	$0.01x + 10$
λ		The minimum value of the storage capacity includes min value of daily traffic intensity, empty containers, and containers which are under clearance custom and repair service at the terminal	-	Cost price of container handling
$y = F(x)$	$0.25x + 50$		$0.02x$	
V	The minimum value of the traffic intensity equals the minimum number of containers in a one single train		Land price of the potential site, construction of container yards, depot, warehouses, grading the site	Electricity, depreciation
$y = F(x)$	-	$-(50x)$		
G_c	-	Inverse interrelation was selected to bound general cost		-
$y = F(x)$	-			
O_c	$-(0.07x)$	$-(8.47x)$	-	

One of the main distinctive features of the developed algorithm is its universality. The universality of the algorithm lies in its application to study different complicated systems, further identification of the parameters with the most destabilizing impact on the system and the final adjustment of their coefficients. Another feature of the developed algorithm is providing the temporary adaptation period to the agents-parameters after storing the selected coefficient of functional dependence into the Excel-file. This is necessary to determine the stability of the system of the main parameters of the dry ports, which have about 100 established interrelations between each other.

With the developed simulation model, a series of experiments was carried out in order to determine the sustainability of the main parameters of the Yiwu dry port. The sustainability of the main parameters is achieved by determining the optimal values of the coefficients of linear functional

interrelations between the presented parameters. In other words, the simulation model dynamically selected the values of the coefficients during the simulation period of 120 months.

The example of the modeling results is presented in Figure 4. The presented figures illustrate that the period of stabilization of the main parameters of the Yiwu dry port equals 20 months.

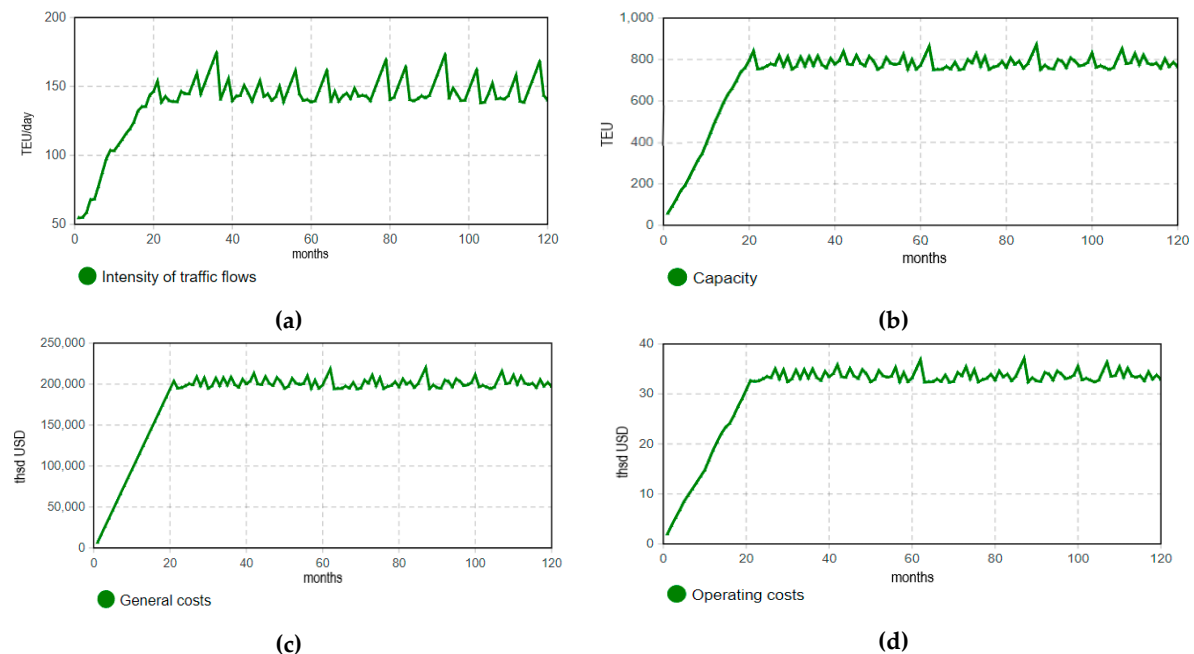


Figure 4. (a) The dynamics of change in the traffic flows intensity, (b) the dynamics of change in the storage capacity, (c) the dynamics of change in the general costs, (d) the dynamics of change in the operating costs.

It means that the simulation model searched for the stability of values by selecting the values of the coefficients of linear functional interrelations between the main parameters of the dry port.

All this points to the adequacy of the developed simulation model and algorithm of adjusting the coefficients of linear functional interrelations between the main parameters of the dry port. Moreover, the modeling results were tested by statistical assessment presented in Tables 3 and 4.

Table 3. An example of statistical assessment of the modeling results.

Statistical Indicators	Calibration Period = 100 Months			
	λ	V	G_c	O_c
mean	155	825	212	36.4
r-factor	0.91	0.88	0.9	0.88
p-factor	0.89	0.85	0.88	0.87
R^2	0.93	0.91	0.87	0.91

Table 4. An example of coefficients of linear functional interrelations.

λ	V	G_c	O_c
	44	0	0.01
0.28		0.011	0.00027
0	315		0
54	0.0001	0	

From the final modeling results, the calibration as a whole suggested that the simulated results have high similarity with estimated values and minor under-prediction. The r-factor shows the desirable measure of the values of parameters' uncertainty which is less than one. Moreover, the p-factor which is close to one indicates that simulation results exactly correspond to the estimated data. The developed simulation model was submitted for further registration of software product to the Russian Federal Institute of Industrial Property.

5. Discussion

The developed methodology to estimate the values of the main parameters of the dry port is fundamentally different from existing practices of feasibility studies on the implementation of complex infrastructure projects at the facility planning. Traditionally, the studies are focused on the expert evaluation of external factors, affecting the operation of complex systems. The selection of the values of the main parameters of the dry port is usually based on the existing average standards or on an expert assessment.

The intensive increase in traffic volumes between China and Europe and the need to develop new transport and logistics infrastructure rapidly form the problem. This problem lies in increasing the reliability of expert assessments and the selection of a sustainable system of the main parameters of the container terminals. Particularly, it is very important for dry ports, which aim to increase the throughput and storage capacities of the seaports.

The present study shows that the wrong prediction or estimation of the parameters of container terminals would hamper the long-term operation of dry ports and increase their operating costs. The main reason lies in ignoring individual external factors, incorrect or inaccurate assessment of the impact of these factors. Moreover, incorrect consideration of the mutual influence of the internal parameters of the dry port would form the problem.

Express evaluation of investment projects in the dry port construction requires an analysis of a variety of external factors and internal parameters from a systemic point of view. However, a detailed analysis of a variety of these factors and parameters, as well as the system of their interrelations, requires considerable costs, such as time costs. To reduce the time cost of a feasibility study of investment projects in a dry port implementation, a system of its main parameters, consisting of a limited number of parameters is proposed. Based on our calculations, the sustainability and balance of the parameters would result in increasing the operational efficiency of a dry port from 45% to 65% [60]. The sufficiency of the selected main parameters of the dry port, which reduce the operating costs has been proved experimentally in the detailed discrete-event (process) simulation models of the seaport-dry port systems [60].

The sustainability of the main parameters of the dry port is achieved as a result of the developed system of direct and inverse interrelations between them. We hypothesize that the description of such connections variety represented as simple linear functional dependences is sufficient to achieve the sustainable state of this system. Furthermore, we show that the change of the parameter's value under the impact of external factors provides the sustainability of the system. In other words, the system of the main parameters of the dry port has the adaptability property.

Moreover, the functional interrelations between the main parameters of the dry port have been justified. Since the interrelations are linear and, practically, they show the fundamental interdependencies between the parameters, the development of these interrelations for specific conditions is a challenging task. We showed that dynamic system consisting of a set of linear functional interrelations achieves the sustainability when the direct and inverse interrelations in the system are correctly described. The developed methodology was tested on real case data.

Future research lies in the application of the obtained calibrated coefficients to determine the optimal values of the dry port's main parameters. To obtain the optimal values, we propose the objective function of the maximum net present value (NPV).

The value of annual costs would result in the indicators of operational costs O_c general costs G_c obtained in one model year. Consequently, $O_{c,k} = O_c/A$, $G_{c,k} = G_c/A$, where $A = T/120$ and $T/120$ is the duration of the modeled period (estimated period) in months, O_c and G_c are the sums of total modeling period. The target function of the developed mathematical model maximizing the NPV value and determined by the following formula,

$$NPV = \sum_{k=1}^{k=A} \left(\frac{T\lambda r_k}{A} - (O_{c,k} + G_{c,k}) \right) \eta_k \rightarrow \max, \quad (9)$$

where λ is the daily number of containers handled in a dry port, r_k is the value of tariff that is current during k -th year, η_k is the discount coefficient. In order to solve this problem, we should apply CPLEX optimization software package. Consequently, the proposed mathematical and simulation models would allow making an express assessment of the main parameters of the dry port at the stage of terminal planning.

Furthermore, the developed simulation model will be tested on real seaport–dry port systems. This test will be carried out in order to obtain a qualitative assessment of the efficiency of the proposed system of the main parameters of the dry port. In other words, this kind of test would evaluate the efficiency of savings in operating costs in case of the applied methodology for calculating the values of these parameters, which is achieved by the sustainable state of the system.

6. Conclusions

This paper shows the importance of dry ports for handling raised traffic volumes in the East-West routes on the One Belt One Road Initiative. It also provides a creative review of the previous studies in the field of dry ports' implementation. The present study proves the lack of efficiency in approaches and methods to select the main parameters of dry ports. Obviously, it could result in reducing the operational efficiency of these intermodal terminals.

The system of the main parameters of the dry port and the established principle interrelations between them are proposed. In order to achieve the sustainability of the proposed system, both the mathematical model and algorithm for adjusting the coefficients of linear functional interrelations between the main parameters of a dry port are developed.

The study proves that the limited number of the main parameters of a dry port and application of simple linear functional interrelations between them achieve the sustainability of the studied system with minimal time costs. It also provides an effective express evaluation of investment projects to construct dry ports with sufficient accuracy of the obtained results.

For practical implementation of the proposed method, both the analytical and simulation models of the dry port's main parameters are developed. These models allow us to carry out the experiments to study the system of the parameters of both dry ports and any other facilities, which are needed to achieve the balance and sustainability of their parameters. The model developed in the simulation platform AnyLogic can be used by different stakeholders, such as port authorities and projecting organizations, to justify the decisions for increasing the storage and throughput capacities of marine terminals.

Author Contributions: D.M., A.R. and H.Z. wrote the manuscript together. D.M. prepared literature review and with the help of A.R. developed a system of the main parameters of the dry port. D.M. and A.R. developed a mathematical model of the dynamic sustainability of the main parameters of a dry port and an algorithm for adjusting the coefficients of linear functional interrelations between the parameters. H.Z. helped with obtaining the data about the Chinese dry port. H.H. provided critical suggestions and inputs for the case study and helped with writing the manuscript.

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