Environmental Factors’ Consideration at Industrial Transportation Organization in the «Seaport – Dry port» System

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Abstract: Currently, container shipping development is directly associated with an increase of warehouse areas for containers’ storage. One of the most successful types of container terminal is an intermodal terminal called a dry port. Main pollution sources during the organization of intermodal transport are considered. A system of dry port parameters, which are recommended for the evaluation of different scenarios for a seaport infrastructure development at the stage of its strategic planning, is proposed in this paper. The authors have developed a method for determining the optimal values of the main dry port parameters by simulation modeling in the programming software Any-Logic. Dependencies that were obtained as a result of modeling experiments prove the adequacy of main selected dry port parameters for the effective scenarios’ evaluation of throughput and handling capacity at existing seaports at the stage of strategic planning and a rational dry port location, allowed ensuring the improvement of the ecological situation in a port city.

Keywords: pollution; environmental factor; dry port; hinterland; intermodal transportation; simulation modeling; parameters

1 Introduction

A change of world container traffic reflects an overall volume dynamics of the world trade. One of the global tendencies is containerization, with an increasing level of global maritime transportation of bulky cargoes [1]. Moreover, at many major ports of the world containers take a main part of all bulky cargoes’ transshipment, e.g., Rotterdam – 80%, Hong Kong 87%, Singapore 92%, Hamburg – 96%, Long Beach – 99% [2].

Within the last twenty years, there have been major changes in the top ten of the largest container ports, e.g., Asian, mainly the Chinese ports are supplanted the European ports. Furthermore, a number of handling cargoes at Chinese ports continues to grow every year [3].

Countries from the Far East region, South and South-East Asia and Western Europe in 2010-2015 have been taking more than 70% of global maritime container traffic. The contribution of other regions in the world sea container volume is much less and does not exceed 10% [4], (Figure 1).

The role of the Russian ports in the world sea container volume is insignificant. As a result from 610.4 million TEU in the global container volume at the Russian seaports in 2015 were handled 3.94 million TEU, or less than 1% [4]. Nowadays, a competitive struggle of major seaports has reached a high tension for container traffic engagement. An increasingly important success factor is the quality of the provided services and the level of logistics services. The global annual growth of container volume is

![Figure 1: Structure of the world container volume of major seaports in the world in 2015.](image_url)
About 10% [4]. Figure 2 shows dynamics of major container seaports in the world in 2014–2015.

Currently, the main reasons of seaports’ «delaying» in Russian Federation is non-compliance of many storage and transshipment facilities to the modern requirements, generating transport flows, impeding movements in coastal areas and on the streets of port cities [5]. Hence, the ability of these ports to further increase of traffic volumes has almost exhausted [6]. Historically, many ports were built near large cities, often in city boundaries, (Figure 3). Cities and seaports have expanded and began to interfere with each other, created infrastructure problems, such as the lack of additional areas for the development of port terminals and port stations, as well as the increased congestion of urban roads [7].

The lack of handling facilities and capacities of seaports leads to significant losses. For example, an average containers’ dwell time in Russian seaports is about 5–7 days [6]. Dry ports’ construction close to seaports will increase their total freight handling with minimal costs for their reconstruction.

Figure 2: Container volume dynamics of major seaport in the world in 2014–2015.

Figure 3: Location of one of the major seaport in residential zone, on example of the Novorossiysk city.

2 Dry port as a way out of the problem

According with V. Roso, dry port is an inland intermodal terminal directly connected to seaport(s) with high capacity transport mean(s), where customers can leave/pick up their standardized units as if directly to a seaport [8]. The main advantages of hinterland are: (a) to increase a throughput and capacity expansion at seaports and (b) timely freight transportation, reduction of total transportation and inventory costs and costs for cargo handling at terminal.

Moreover, one of the main advantages of a dry port is the solution of environmental and social urban problems at the seaport location, as a result of a partial transfer of loading and unloading operations in distant areas from residential areas, as well as due to the creation of additional jobs at the region [9]. For the selection of a dry port location in Russian Federation on stage of its strategic planning, significant impact is given to environmental protection factors, considering in the international programs aimed to environmental protection and environmental legislation formation [7].

As a result of foreign trade reinforcement and economic relations between two countries, whereby, during organization of distant transportation used container ships, regularly observed an increase of TEU ships’ capacity [7]. However, this factor adversely effects to the seaport infrastructure development, as the workloads are increasing on seaport infrastructure and the port transport network is involved in the ports’ service.

Changes in meteorological conditions in water areas in major seaports increase irregularity of ships’ arrivals [10]. In this regard, there is container lorry dwell time, leading to an increase of carbon dioxide emissions into the atmosphere, which adversely effects the image of marine freight terminals. Furthermore, traffic congestion not only creates a negative impact on the environment, but also limits seaports’ throughput [11]. Hinterland development will improve transport and an ecological situation in city of a dry port location.

Nowadays, one of the main sources of environmental pollution with a carbon dioxide (CO$_2$) is a transport sector [12]. It takes of 26.5% from total emissions’ distribution by sector. Moreover, an automobile transport takes 23.1%. In a program by the Global Fuel Economy Initiative there were predictions for the volume of carbon dioxide emissions by industry [13]. Figure 4 shows that transport is second only to the energy industry in a predicted growth, while a total growth of transport sector in CO$_2$ emissions can be 35%.
At the modern major industrial centers one of the most common types of environmental pollution, which constantly functions and adversely affects human life is noise. According to the Russian Federal Law from May 14, 1990 No 96-FL «About the protection of an atmospheric air» [14] noise exposure refers to a harmful physical impact on an atmospheric air.

One of the regular sources of environmental pollution is transport noise, because of the operation of automobile engines, wheels’, bumps of rail rolling stock on rail joints and etc. [15]. For example, in the Moscow, experiments were carried out to assess the impact of excessive noise on population from following sources: automobile transport - 58%; construction facility - 19%; non-production and industrial facilities – 18%; air transport - 3%; rail transport - 2% [16]. Furthermore, the excess of a noise level of motor transport in some industrial centers is on average [17].

The volume of solid domestic waste (SDW) almost in all countries has been increasing annually; there is a complication of its structure. Consequently, population attitude to the traditional methods of waste disposal becomes more negative [18]. Most sharply, this problem is shown in large industrial cities of the Russian Federation. Russia annually produces about 3.8 billion tons of all types of waste. SDW’ quantity is 63 million tons per year (an average of 445 kg per person) [19].

The predominant form of SDW in Russia is paper and cardboard – 35% [20], which are used for goods’ packaging and further containers’ stuffing in the area of a dry port as well. A solid domestic waste is recycled only 3–4%, industrial 35%. Basically, the garbage delivers at dumps or the SDW’ landfills- they are in Russia about 11 thousand. Hence, they have about 82 billion tons of waste.

In view of the main advantages of the dry ports, it can be concluded that this terminal is aimed not only to increase the throughput and handling of seaports, but is also intended to solve environmental problems in the region of seaport location.

### 3 Main parameters of a dry port

Realizing these benefits can be achieved if the moment of a dry port implementation coincides with the moment when throughput of a seaport is not able to pass without delays in transport and freight flows of increased intensity, thereby increasing the environmental pollution levels from carbon dioxide (CO2), from noise pollution caused by lorries’ operation in the terminal areas and from solid domestic waste during containers’ stuffing, as well as on condition of the rational location selection of dry ports, optimal capacity and technical equipment. An adoption of relevant decisions during strategic planning requires an assessment of the following main parameters of a dry port: intensity and irregularity of the input freight flows and vehicles; dry port location and route capacity of transport communications between a seaport and dry port; size of a dry port in a plan and the handling capacity of a container terminal; an ecological factor during dry port placement; costs for dry port construction and operation of «seaport-dry port» system.

**Intensity of the input freight and vehicle flows (λ)** – an increase of intensity of input flows in seaports (λ) determines the necessity of increased throughput, handling capacity and total capacity. Results of statistical analysis of freight flow in the transport nodes show that with an increase of freight flow intensity there is a decrease of its irregularity, as a result of the discrete flow reduction and size approximation of the freight consignment to an average value. This phenomenon is observed until exhaustion of the throughput reserves and the capacity of transport units of the node, after which, as a result of delays in freight flow processing, there is an increase of its irregularity and reduction of freight transportation quality.

To ensure the required quality of transportation service by increase the intensity of input freight flow of a seaport, it is necessary to build a dry port with higher total capacity and consequently, larger in size. The size of a dry port may be limited by conditions of geographic area, as well as ecological factors in the region of its location.

However, a dry port location into a residential zone with a high intensity of input vehicles’ flows is impossible, in view of increased levels of noise pollution, sources of which are the engines of container lorry. The increased intensity of an input traffic flow leads to the raising of SDW volumes. Here arrives a large amount of cargo, which must...
be packed for container stuffing, conversely, some consignees prefer containers’ unstuffing on a dry port territory, in a small volume of a shipment.

Irregularity of the input freight and vehicle flows (Xir) – irregularity is one of the fundamental parameters of traffic flow and mainly determines a necessity for reserves of throughput and handling capacity of transport units. The value of irregularity coefficient (Xir), which is a component for separate directions of freight flows 2.0 and higher, is dependent on the market factors, seasonality of transportation, the consistency of work level of the port railway station and private rail tracks, as well as a number of other factors [21]. The increased capacity at a seaport terminal through the construction of dry ports can reduce the irregularity of traffic flows and increase the quality (timely) of cargo delivery.

The increased irregularity of input vehicles’ flow results to an increase of emissions by diesel locomotives – 800 g per hour [22] and 6 kg per hour by a container lorry [23] that adversely effects on the surroundings of a dry port. As a result, there are queues of vehicles, waiting at the checkpoint gate of hinterland.

Freight flows’ handling with a high irregularity of seaport terminals require a selection of dry port constructions with higher capacity, which is located at a short distance from the seaport, and (or) in area with favorable topographical conditions.

Increase of distance or a selection of area with less favorable topographical conditions will be possible, if requirements satisfy the freight owners and timely transportations is offset by increased price. Reduction of general costs on the dry port construction in such conditions is achieved by the use of modern flexible work technology of the transport-technological system «sea port – dry port» – port railway station, which allows rational use of throughput reserves and handling capacity of the system [24].

Route of a transport communications between sea and dry ports. Route characterized by the length of railway connection (L), as well as the topographical conditions of the area and its passage. Route extension increases the time of freight transportation between seaports, which potentially reduces the timeliness of transport services and also increases the general and operating costs of the system «sea port – dry port». High intensity and (or) irregularity of the freight flows in the considered system involves the selection of the shortest route, in order to reduce dwell time and delays of vehicles and freight, thereby to reduce the level of environment pollution.

Location of a dry port (ESM). Location of a dry port determines the route length of transport communications between seaport and dry port, as well as the total cost of creation and operation of a dry port. Necessity to locate a dry port in the area with less favorable topographical conditions is determined by the necessity of highly intense freight flow handling, as well as the need to provide high values of shipment timeliness.

On account of the ecological factor at a selection of a dry port location outside the city, it’s necessary to consider the existence of reservoirs, rivers, springs, etc. for the planned territory for a dry port construction. If we choose the territory for dry port location at a short distance from the seaport, with availability of reservoirs, it’s necessary to build wastewater treatment plants for wastewater filtration.

Capacity (V) is size of the dry port in a plan and a handling capacity of terminal (n). These are interrelated parameters, which are determined by the amount of total costs for the creation and operation of dry ports. These parameters are selected depending on the intensity and irregularity of the freight flow and topographic conditions of the dry port location area.

Environmental factor (Ef). This parameter assesses the sum of environmental payments after a dry port implementation, in dollars. We assumed that the transfer of environmentally unsafe and a polluting operations to a distant territory of a dry port from residential areas. Moreover, auto traffic volumes’ transfer to this territory, significantly decreases the ecological loading on cities located close to a seaports and reduces environmental fees and penalties. At a low level of an ecological factor (pollution) it’s necessary to locate dry port outside the residential zone, taking into account the increase of general costs for purification systems and SDW’ processing. Currently, most of SDW is transported to the landfill of solid waste. Moreover, the main disadvantages of SDW’ dumping are constant environmental danger (density of SDW 0.15 t/m³), increasing costs for SDW’ dumping, irrational land resources utilization [25], that limited the variability of dry port location.

Total costs for construction and operation of dry port. The amount of general costs (Cg) for dry ports’ construction depends on the topographic conditions in the area of the estimated location of a dry port, its capacity and size in a plan, the handling capacity (technical equipment), route length between the dry port and seaport, throughput of transport communications and level of an environmental pollution. Operational costs (Co) include, in addition, cost for maintenance of constructed infrastructure, as well as operating cost of transport and transport-cargo facilities, cost for storage and freight’s handling in the dry port, freights’ transportation between seaport and dry port, losses from dwell time of transport and handling fa-
Table 1: Matrix of interrelations between main parameters of a dry port.

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<tr>
<th>Parameters</th>
<th>$\lambda$</th>
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Note: "+" means an increase of the parameter value, "−" – decrease. For a quality parameter ($E_M$) "+" indicates favorable topographic conditions "−" – non-favorable conditions.

...cilities [26], losses as a result of violation of the requirements of timely freight delivery.

The presented main parameters of a dry port, selected at the stage of its strategic planning are interconnected between each other and formed the system. Matrix of quality interdependencies in system of dry port parameters is presented at Table 1.

The authors propose to apply developed system of the main parameters of a dry port in case of a simulation model construction of the port terminal, which includes a dry port, and determination by the model an optimal correlation of these parameters by criterion of minimum prime cost of cargoes’ handling.

4 Simulation model of the «seaport – dry port» system

As determination method of optimal values of the main parameters of a dry port, the simulation modelling method was selected [27], allowing take into account many additional individual factors and characteristics of container terminals’ operation.

Furthermore, the modern instruments for a simulation models’ construction allow not only to describe the operation technology of container terminals with accuracy of a specific container (agent-based modeling), but also to make decisions of strategic (system dynamics modeling) and tactical (process simulation) levels [28]. For example, the multi-approach system, called AnyLogic [29], allows us to combine all three paradigms of simulation modelling in the same model. In addition, to simulate the interrelations of parameters’ system of a dry port at the macro level, the simulation model also calculated the values of these parameters with accuracy to separate technological operations with specific containers.

At present, this paper considers a part of model, constructed by the process approach and intended for operation simulation of the «seaport – dry port» system. This process simulation model is used for a quantitative description of the main dependencies between the parameters of a dry port.

Only a discrete parameter of the system is a parameter that determines the dry port location. This parameter in the model is proposed to describe the set of points on the situational plan of the land allotment, (Figure 5). Each variant of a dry port on the situational plan characterized by the general and operational costs, depending on a dry port capacity, the terrain, length of transport communications (route), planned container volume (intensity and irregularity of container traffic flow). Table 2 presents model...
Table 2: Model values of main parameters of dry port.

<table>
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<tr>
<th>Square number</th>
<th>Scenario 1, $V = 1$ thsd TEU</th>
<th>Scenario 2, $V = 2$ thsd TEU</th>
<th>Scenario 3, $V = 3$ thsd TEU</th>
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Figure 5: Situational plan of area and a potential location of dry port

The developed method of determination for the optimal values of main parameters of a dry port on the basis of simulation modelling consists of two stages. During the first stage, the maximum values of throughput and handling capacity of existing seaport, which provide the specified quantity and quality (timeliness) of freight transportation, are determined. During the second stage, the optimal values of parameters in the dry port are calculated. According to them, the required characteristics of freight traffic, including the prediction of the intensity increase, are achieved.

Moreover, an efficiency evaluation of the method and validity of the proposed system of main parameters for dry ports was carried out on a model example of the «seaport – dry port» system. The system includes three containers areas – berth of a seaport, container areas of a seaport and dry port. Each area has operations related with container traffic volumes’ handling upon arrival and departure. Container ships, arriving at a seaport, moored at two berths, each of them equipped by two container cranes. Lay-out of tracks of railway port station consists of four receiving and departure tracks with a capacity up to 55 railcars. Freight operations with containers are implementing at four loading areas – two for each berths. Between berths and container area of a seaport, containers’ transportation implements by shuttle trains with 25 railcars in a train, between berths and dry port with 40 railcars in a train. Furthermore, between berth and container area of a seaport, containers’ transportation implements by container lorry with a quantity of 6 units.

The container area of a seaport is equipped by four container cranes. Lay-out of tracks of railway port station consists of six receiving and departure tracks. Loading and unloading operations are carried out by an overhead crane. The container area of a dry port has six container cranes. Capacity of railway tracks at railway station of a dry port allows receiving from an external network train up to 55 railcars. After a ship’s arrival at the water area of a seaport, checking of free berth availability takes place.
If berths are busy, the ships are waiting at anchorage area the berths’ release. Loading and unloading operations at a seaport can be organized by direct variant (ship – railcar) or warehousing (ship – berth – railcar; container lorry – container area of a seaport).

After containers’ placement at areas of a seaport and dry port, they have commercial and partially freight operations. From the container area of a dry port containers depart to a seaport by rail transport, as well as to customers by auto or rail transport.

The feature of simulation model construction is a combination utilization of discrete event (process) and agent based approaches, allowing just to describe the properties of the individual equipment and devices, freight units and rolling stock units, so to simulate the technological processes. The developed model of the «seaport – dry port» system consist of three agents’ groups: dynamic agents (entities), containing the characteristics of containers, ships, railcars, trains; statistical agents (service equipment and devices), imitating berths, container areas, cranes, straddle carriers, container lorry; managing agents – dispatchers, regulating container flows and vehicles, as well as the interaction of different agents in the model.

According to the constructed model, a series of experiments were conducted, in order to evaluate the seaport volume, before and after dry port implementation into the simulation model. Simulation experiments were held for different values of ship arrival intensity, changing at a range from 10 to 14 ships per month and coefficient of irregularity of incoming flow ranging from 1.15 to 1.5.

Since then, time costs for technological operations in a simulation model were specified with distribution laws of a random variable. It was possible to reduce the dispersion of received results after conducting 10 runs of the model with the same input data. To exclude minus values of the time interval between the moments of ship arrival in port, possible when using the normal distribution law of random variable, the model was used as a mechanism to verify the generated interval values on the negativity. The duration of the simulated period in the experiments was estimated to be equal for one month.

5 Simulation modelling results

The maximum throughput of seaport was limited by the capacity of adopted waters, which equals to six ships. The maximum throughput of a simulated seaport is 14 ships per month, because the increase in arriving ship numbers at seaport does not increase its volume. After a dry port implementation, which allowed having the optimum capacity for respective traffic, there is an almost linear increase of volume in the simulated system from 42000 TEU to 66000 TEU. This allows us to conclude that there is an adequacy in the developed simulation model and the correctness of proposed system of the main parameters in a dry port.

In the modeling process, each time interval between the moments of ship arrival at the port irregularity coefficient ($K_{ir}$) of this interval were conducted ten runs of the model with the duration of the simulated period is one month. Results of data averaging, obtained in the experiments shows that average ships’ dwell time at anchorage area decreased from 6800 min to 4300 min.

The optimal moment of a dry port implementation as a model example, which occurs with the increase of monthly intensity of ships arrival at the port up to 14 with capacity 4000 TEU, is determined by the prime cost change of container and operating costs in a simulated system.

After the determination of the maximum handling capacity at seaport, optimum values of proposed system of main parameters in dry port, depending on its location, capacity of area and handling capacity were calculated. The selection of optimal combination of parameter values for the dry port (table 1) is based on the criterion of operating costs minimum in the «seaport – dry port» system (prime cost). Operating costs include costs for vessels demurrage and railway rolling stock in system and costs for containers storage in the system.

For the adopted input data of the optimal dry port location in model experiment have consistently been quadrants 8.1, 8.2, 7.3 and 7.4, (Figure 5), i.e. the model «select» dry port location on the minimum distance from seaport. This distance model has sought to reduce with increased intensity and irregularity of input freight flow and the capacity of the dry port.

Analysis of the obtained results shows, that dry port construction allowed to minimize the average ships’ dwell time at anchorage area in one and a half times. After dry port implementation into simulation model with optimal values of its main parameters, prime cost reduced on 33%.

Prime cost reduction, as a result of full reduction of losses connected with dwell time of vehicles (ships and rolling stock) and loading and unloading mechanisms reduce the container supply and the time of their storage in ports.
6 Discussion

Since transportation sector is one of the major sources of pollution – especially CO\(_2\) emissions – it is considered as one of the most important subjects to reduce its volume of pollution. In addition, according to the report about trends in global CO\(_2\) emissions [30], traffic congestion has increased significantly during the last two decades. Congestion can be seen as increased queues e.g. at seaport's gates or cities. Queues occur whenever instantaneous demand exceeds the capacity of the transport network e.g. road network. In this paper, decrease of vehicles’ dwell time allowed reducing environmental pressure on zone of a dry port location.

A promising direction of this research, in the authors’ opinion is evaluation of solid waste emission and noise pollution in zones of the dry ports’ location by means of agent based approach in the field of simulation modelling. Moreover, for the visual interrelations’ presentation of main parameters of a dry port it’s proposed creating system dynamic model. The main goal of this model is to show how intensity and irregularity of incoming traffic volumes, distance and dry port’s capacity influence on ecological situation of zone where dry port located.

The developed method allows minimizing general and operating during dry port construction and it is advisable to use for justification of investment decisions for the balanced development of transport and logistics infrastructure in port cities.

7 Conclusion

Main problems of logistics infrastructure functioning in major port cities are uneven development of transport and logistics infrastructure in the regions, insufficient throughput of existing ports, limited opportunities to increase handling capacity of sea ports because of location of most major ports in close proximity to residential areas. Furthermore, for Russian conditions it’s a high irregularity of incoming freight and railcar flow, reducing the usage efficiency of available handling capacity and capacities of seaports, and, hence, deteriorating the timeliness indicators of freight flow processing at the ports.

One of the topical issues in the field of logistics is the development of multimodal container terminals, organized on the principle of a dry port. This idea came from the USA and its meaning, to offload port areas with large concentrations of freights. Containers by rail are sent to the inland, where they pass further handling, customs clearance and go to the destinations of different vehicle types. Obviously, in each case, the practicability of the dry port organization is defined by the relevant feasibility study.

Moreover, hinterlands’ construction is a way to minimize negative impact on environment through an increase of throughput and handling capacity of sea port at zones of its limited territorial development. Inevitable traffic congestion at port areas reduces throughput of seaports’ access and negatively effects on ecosystems in these zones. Dry port implementation is a way of harmful effects reduction on the environment due to decrease of vehicles’ queues on the way of seaport and switching of freight traffic volumes from road transport to rail, which is more environmentally friendly.

The system of dry port parameters, which are recommended for different scenarios evaluation of seaport infrastructure development at the stage of strategic planning is proposed in this paper. The authors have developed the method of optimal values’ determination of main dry port parameters with simulation modeling application in the programming software AnyLogic. The results of dry port implementation showed decrease of vehicles dwell time that helps to improve ecological situation at the city of seaport location. Furthermore, optimal dry ports’ locations were obtained according to the preserve of timely transportation and decrease of environmental tension on the areas of potential terminal location. The perspective direction of method and simulation model improvement in this paper is the inclusion of time factor to determine the optimal sequence of transport and logistics infrastructure development in port cities based on definition of optimal values dynamics of main parameters of a dry port.

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