Impact of the Internet of Things on the formation of a model for optimizing port terminal operations

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Abstract. The research established that new business conditions have radically changed relations between the participants in the transport process. The Coronavirus Disease Pandemic (COVID-19) has revealed the lag of most maritime enterprises in the digitalization process. The problems of interaction and competitions caused by the transformation of stereotypes of behavior of transport services consumers have become more acute. The need for new approaches to optimizing port terminal operations has determined the purpose of the research. The problem is multifaceted, that is why the article analyzes statistics; a survey of top managers of companies providing port services was conducted. The key requirements of customers are the speed of service, organization of terminal operation on the concept of the Internet of Things, digital competence of company employees that affects the speed and quality of services. In order to optimize terminal operations, the authors suggest applying a mathematical model providing the competent planning of terminal operations with a given probability of customer service. The authors suggest increasing the cooperation between employers and educational institutions in the development of digital competence in students and application of the Internet of Things in the Maritime Industry.

1. Introduction
Today, maritime transport companies find themselves in difficult conditions under the influence of external factors. One of the key factors is the COVID-19 pandemic, which is a catalyst for the transformation of the industry model. The maritime business should follow new rules that have radically changed the relations between the participants in the transport process. The long-brewing contradiction consists in the lag of certain sectors from the digitalization process. In particular, many companies were completely unprepared to implement a remote work format. The equipment of workplaces at home, installation of programs for cooperation with business partners were urgently resolved. There are a number of enterprises that have managed to reorganize their business and ensure the smooth operation of the supply chain. At the same time, even the leaders said that measures aimed at further digitization of the business are required. In addition, it is worth emphasizing the current problem of building mutually fruitful relations between business partners and intensifying competition due to many reasons, including the transformation of stereotypes of behavior of consumers.

According to the UN data on trade and development [1], from 2019 to 2024, the average growth of world trade will be 3.4%. In 2018, the growth rate of world trade volumes was 3.7%, in 2019 - 1.0%, and in 2020 - 2.9% [2]. In 2021, the growth will be 3.7% (the growth rate can reach the level of 2018), which indicates the recovery.
New trends in the port competition can be divided into intra-port and inter-port. The in-port ones are characterized by key competitiveness criteria such as the time for servicing a ship (including the time for loading and unloading and ancillary works), tariffs and port dues.

In addition, inter-port competition is influenced by economic and political factors, and the possibility of ensuring effective interaction with the transport networks of the region.

Interesting is the study carried out by the World Bank [3] which identified a sharp decline in the global index of business confidence, which is an indisputable proof of the transformation of the business environment. Changes in the behavior of consumers of the maritime industry cause concerns: the transfer of purchases to the Internet business will affect the structure and volumes of traffic [4, 5, 6].

The use of models aimed at satisfying the requirements of the economic system, which is subject to rapid globalization and digital transformation is relevant.

2. Materials and Methods
Given the multifaceted nature of the problem, a retrospective analysis of statistical data was carried out. In order to identify changes in the requirements imposed by the clients, the authors conducted a survey through in-depth telephone interviews with employees of forwarding and agency companies, as key links in the logistics service of a sea vessel in the port. The respondents were top managers of marine companies that provide port (terminal) services.

3. Identification of key transformations of the external business environment of marine companies in the field of terminal services
In order to determine the current situation in the port business, we conducted a study aimed to identify the impact of the pandemic and digitalization on the operation of port terminals. Analyze the cargo turnover of the Russian seaports for 2017-2020, using the data in [7] (Figure 1). Figure 1 shows an interesting trend: in the Arctic basin, there is an increase from 73.4 million tons in 2017 to 104.8 million tons in 2019 and a decrease to 96.0 million tons in 2020. In the Baltic basin, we see a completely different picture: a slight decrease in 2018, and an increase in 2019. By the end of 2020, a drop in freight turnover is evident. In the Azov-Black Sea basin, an increase in the volume of cargoes from 2017 to 2018 can be observed. Since 2019, this indicator has been steadily decreasing.

![Figure 1. Dynamics of cargo turnover of Russian seaports for the period of 2017-2020 by basin, million tons [7]](image)

A steady growth trend throughout the entire period in the Caspian and Far Eastern basins can be observed due to many factors, including the range of processed goods. For example, a pronounced
drop can be observed in the Azov-Black Sea basin against the same sharp decrease in the volume of oil and oil products (Figure 2).

![Figure 2. Dynamics of cargo turnover of seaports according to the main nomenclature of liquid cargo for the period of 2019-2020, million tons [7]](image)

For dry cargo (ore, coal, coke, timber, grain, containerized cargo, mineral fertilizers), a slight increase is observed in 2020 (within the range from one to four million tons, and only for grain, the turnover increased from 38.6 million tons up to 50.3 million tons) [7].

An assessment of the cargo turnover of seaports revealed the following trends. Compared to 2019, in 2020, exports increased from 76.4% to 78.8%, while imports decreased from 4.6% to 4.5%. The volumes of transit cargo decreased from 7.8% in 2019 to 7.5% in 2020. The volumes of cabotage cargo fell from 11.2% to 9.2% (Figure 3).

In order to identify the key factors of competitiveness of port terminals, studies were carried out. The authors used the survey method; the respondents were top managers of agency and forwarding companies that have been operating in this sector for at least ten years and occupying market shares from 3% to 35%.

![Figure 3. Cargo turnover of seaports according to the directions, % [7]](image)

The following key questions were asked: have the requirements of consumers changed over the past five years; how have they changed. It was revealed that
- there are changes in the requirements for the quality of services, including the speed of service;
- customers are focused on comprehensive services;
- for a number of years, customers prefer the delivery of invoices via e-mail, instant messengers, electronic document management systems, working with shipping lines and terminals that have implemented the concept of the Internet of Things.
The survey results revealed that customers have been focusing on the speed of service provision and want to communicate through electronic document management. In addition, there is a steady trend of digitalization of terminal services [4, 5], which should also be taken into account when organizing the port terminal operations.

4. The using of mass service model with a waiting with a limited length of line for optimization the operation of a port terminal

The port terminal can be represented as a queuing system in which customers are waiting for their services, and there are queue length restrictions. Denials of service occur when the number of requests \( k \) (the number of vessels waiting for free berths) exceeds the sum of the number of service channels (the channel is a crew of dock machine operators) and the maximum possible queue length \( m \) (the number of berths). The speed of service is a very important indicator. To optimize the operation of the port terminal, a mathematical model [8, 9] was applied. The probability or the downtime of the service channels is determined in the absence of ships (1):

\[
P_0 = 1 - \left( \sum_{k=0}^{n_p} \frac{\rho^k}{k!} \right) + \frac{\rho^{n+1}}{n!} \left( 1 - \frac{\rho}{n} \right)^m \Bigg), k = 0
\]

The probability of denial of service, or the proportion of lost orders (departure of the vessel to another port) is calculated under the fully loaded system (2):

\[
P_d = P_{n+m} = \frac{\rho^{n+m}}{n!} \cdot \frac{n!}{(n-\rho)^m} P_0, k = n+m.
\]

The probability of service, or the relative throughput of the terminal is calculated by formula (3):

\[
P_{ser} = 1 - P_d.
\]

The absolute throughput of the terminal is calculated by formula (4):

\[
A = P_{ser} \cdot \lambda.
\]

The average number of employees servicing the berths is calculated by formula (5):

\[
\bar{n}_e = \frac{A}{\mu} = \rho P_{ser}.
\]

The average number of requests in the queue (the number of ships waiting for service) is calculated by formula (6):

\[
\bar{1}_q = \frac{\rho^{n+1}}{n!} \left[ 1 - (m+1) \left( \frac{\rho}{n} \right)^m + m \left( \frac{\rho}{n} \right)^{n+1} \right].
\]

The average number of requests in the system (the totality of waiting ships and ships already in service) is calculated by formula (7):

\[
\bar{z} = \bar{1}_q + \bar{n}_e.
\]
The probability of queues in the terminal system is calculated by formula (8):

\[ P_q = \sum_{k=n+1}^{n+m} P_k = P_0 \frac{\rho^{n+1}}{n!(n-\rho)} \left[ 1 - \left( \frac{\rho}{n} \right)^n \right]. \]

The probability that all berths are busy with servicing and a new request will have to queue is calculated by formula (9):

\[ P_b = \sum_{k=n}^{n+m} P_k = P_0 \frac{\rho^n}{n!(n-\rho)} \left[ n - \rho \left( \frac{\rho}{n} \right)^m \right]. \]

The average time of waiting for service is calculated by formula (10):

\[ \bar{t}_q = \frac{P_b}{\mu(n-\rho)}. \]

The average time of a request being in the system (the ship's parking time in the port, which is the sum of the time the ship is loaded and unloaded, and the time spent on auxiliary operations) is calculated by formula (11):

\[ \bar{t}_p = \bar{t}_q + \bar{t}_s. \]

Apply the above model for the operation of the port terminal under the following conditions (an example demonstrating only the calculation algorithm). According to the terminal's operating schedule based on requests and notices of readiness received from vessels, vessels arrive for loading and unloading operations with an intensity \( \lambda = 6 \) vessels per day. The number of berths ready to serve is \( m = 2 \). Four crews service them, and each crew can handle one vessel during the working day with a shift of 12 hours. Determine the number of berths satisfying the condition: the probability of complete servicing must be at least 0.97. Applying the above formulas (1) - (11), we have the following results presented in Table 1.

| Number of berths (m) | Calculated probability values | If the calculated values fulfil the specified probability value: \( P \geq 0.97 \) |
|---------------------|------------------------------|-----------------------------------------------|
| 2                   | 0.925                        | no                                            |
| 3                   | 0.952                        | no                                            |
| 4                   | 0.972                        | yes                                           |

To fulfill the given conditions, it is necessary to find additional berths, which is difficult. Therefore, using this model, it is possible to calculate (with a given probability) the number of crews, subject to \( 1 \leq n \leq \infty \) (\( \infty \) is limited by the number of ship holds, the availability of technological equipment used for loading and unloading operations), which will make it possible to draw up a terminal operation plan satisfying the given values of probability

5. Conclusion
Considering that it is the speed of service that is the key criterion according to which customers evaluate the terminal operation, the relevance of the model is indisputable. It should be emphasized that one of the main conditions for the effective development of port terminals is digital technologies, which requires the improvement of personnel training. Workers should be trained through refresher courses. Companies should cooperate specialized educational institutions to organize the educational process in such a way as to develop skills and abilities required to work in the digital environment in accordance with the needs of a particular terminal (a target option is possible. training). New knowledge will allow onshore personnel to participate in the implementation of the unmanned vessel concept [10]. It is necessary to pay attention to the fact that recently many foreign ports have been successfully developing within the concept of the Internet of Things. This allows them to optimize the operation of the terminal and unload access roads, to combine information flows, reducing the speed of vessel’s service [11]. Taking into account the global scale of digitalization of the maritime industry and opinions of customers, one of the key factors in the successful development of domestic terminals is the Internet of Things technologies. Thus, it is recommended to include IoT technologies in the general customer service chain when planning terminal operations on the basis of the model proposed, which will improve its effectiveness.

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