Model for Evaluating the Efficiency of Seaports Development Projects Based on the Quality 4.0 Information and Analytical System

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Abstract

In modern conditions of the development of the transport system, there is strong competition between seaports offering cargo and ship handling services. This requires the search and implementation of new information technology and software models of management solutions. The objective of the study is to project a technical specification for the development of an information system that could automatically calculate the competitiveness of port services in the Quality 4.0 software model which will make the process of transshipment of goods and handling ships more dynamic and high-tech. The purpose of the article is to project the technical specification for the development of an information system for calculating and evaluating the effectiveness of investment development projects proposed for implementation in the seaport. Also, the research tasks are directed to identify modern software models for assessing competitiveness within the framework of using the model Quality 4.0 based on the developed information system to calculate indicators of port operation in an automatic mode and to identify the most weighty indicators, to determine the compliance of key indicators of port development with the quality of services provided within the framework of investment development projects based on the use of the technical specification for the development of information system. It is proposed to use the Quality Function Deployment method within the framework of the House of Quality software model for automated calculations of the competitiveness of port services, taking into account the proposed technical specification for information system development.

Keywords 1

Information technology, project management, technical specification, seaport, Quality 4.0 software model

1. Introduction

The seaport plays an important role in the modern system of goods movement. Trade operations are carried out within the framework of foreign trade agreements between countries for many of which maritime communication is the only alternative to the delivery of goods considering the lower cost of transportation by sea compared to other modes of transport.

The seaport is a cargo accumulator for rail and road transport, creating new cargo flows for them.

It is impossible not to note the predominant role of the seaport in the economic growth of the state. To reduce the cost of shipping their products, many manufacturers locate their production in port cities, which greatly reduces the cost of logistics costs [1].

Seaports also provide an incentive for the development of related industries [2]. This is reinforced by the fact that investments in port development projects create additional demand in other sectors of

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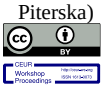

the economy, and also contribute to the creation of new jobs not only in the port but also in other enterprises [3].

2. Analysis of Literature Data and Resolving the Problem

These areas in the port development are reflected in the Strategy for the Development of Sea Ports of Ukraine for the period up to 2038 [4], the National Transport Strategy of Ukraine until 2030 [5], as well as various conceptual solutions and scientific research related to improving the efficiency of port activities [6]. The following areas are classified as priority initiatives for the development of ports: increasing the capacity of seaports to serve ships of large gross tonnage; preparation of a regulatory framework for public-private partnership in the field of maritime transport; implementation of pilot port concession projects; reducing the time for cargo handling in seaports; support for the exchange of electronic data with ports and other organizations (NCTS system), the introduction of the Single Window principle, the use of information technology in the port's operations; proposal of a new port dues methodology; implementation of the principles of corporate governance and targeted financing; implementation of the maritime safety action plan [7-10].

At the same time, special attention is paid to assessing the impact of ports on the economic processes of the state. However, in our opinion, in several scientific articles devoted to the development of ports, the questions of improving the competitiveness of services in the port sector, the use of modern information technologies to assess their quality are insufficiently studied.

One of the innovative technological trends is the desire of enterprises to switch to fully automated digital production, controlled by intelligent systems in real-time and in constant contact with the external environment [11-14]. The interaction of long-studied ways of organizing production and new automated possibilities for managing processes throughout the entire life cycle of products is the basis of Industry 4.0 [15-17].

For the effective development of ports in a difficult competitive environment, they need to adapt to dynamically changing environmental conditions [18].

To meet the transport and export-import needs of the state, seaports must provide internationally competitive port infrastructure and provide quality services based on the use of information technology within the technical specification for the automated calculation of the competitiveness of the seaport [19, 20].

3. The Purpose and Objectives of the Research

The purpose of the article is to project the technical specification for the development of an information system for efficient calculating and assessment of investment development projects proposed for implementation in the seaport.

We have set the following tasks in the research: to prepare a technical specification for the development of an information system that could automatically calculate the competitiveness of port services, to clarify the concept of quality of services in seaport development projects, to identify modern software models for assessing competitiveness within the framework of using the software model Quality 4.0 based on the information system to calculate indicators of port operation in an automated mode, to determine the compliance of key indicators of port development with the quality of services provided within the framework of investment development projects based on the use of the technical specification for the development of an information system for automated calculations of the competitiveness of port services.

4. Materials and Methods of the Research

The indicator of competitiveness is the characteristic used to assess the economic efficiency of enterprises [21]. However, you need to pay attention that this concept is not fixed at the government level, we have no single definition of what is meant by this concept in the framework of port activities. Also, in scientific articles, the issues of the competitiveness of seaports and indicators for

their assessment have not been sufficiently studied. One of the main indicators of product competitiveness is its quality [22].

The competitiveness of a seaport is understood as the ability of a seaport to provide services arising from merchant shipping concerning servicing ships, transporting goods and passengers, which, in terms of price and non-price (qualitative and quantitative) characteristics, are more attractive to consumers (shipowners, shippers and passengers), than the services of another seaport [23].

It should be noted that the concept of the competitiveness of a seaport can be considered depending on the subject of competition and the scale of the competitive market being assessed at different levels - as the competitiveness of the seaports of the state as a whole, as the competitiveness of an individual seaport and as the competitiveness of an enterprise or its specific service provided by the specified enterprise in a single port [24].

Figure 1 shows the levels of assessment of the competitiveness of ports depending on the subject of competition, as well as the scale of the assessed competitive market [25, 26].

Figure 1: Levels of competitiveness of seaports

In modern conditions of the development of the transport system, there is strong competition between seaports offering cargo and ship handling services. This requires the search for and implementation of new technologies and management solutions based on the use of modern information technologies, which will ensure the high quality and competitiveness of port services, make the process of cargo transshipment and ship handling more dynamic and high-tech.

The main activity of seaports is the orientation of all stages of the transshipment process to satisfy the needs of stakeholders of port services - cargo owners, shipowners and the state as a whole.

It is proposed to use the QFD (Quality Function Deployment) method or structuring (deployment) of the quality function to assess the quality of services provided by the port.

There are many publications devoted to the use of the QFD methodology in various areas of production and services. However, the issues of using this methodology in assessing the competitiveness of services provided by the port have not been fully studied.

The first and most important component of QFD is the House of Quality (HoQ) model. The model of “House of Quality” is a universal tool that allows within the framework of a single model to perform a comprehensive analysis of both the consumer properties of an object and the characteristics that determine the method of implementing seaport services and the possibility of using information technologies [27-29]. The essence of the QFD method concerning the port will be considered as

consistent actions of enterprises providing services in the seaport to turn emerging consumer requests (cargo owners, shipowners) regarding the quality of services into technical requirements for it, processes and equipment operating in the port.

The implementation of the QFD method is more efficient when introducing innovative digital technologies into the management of the seaport. Innovations based on the best world achievements, enshrined in international standards and methods of quality management, significantly increase the effectiveness of both new and existing technologies and generally increase the competitiveness of enterprises. One of these modern approaches is the concept of Quality 4.0 (Figure 2) [30-33].

Quality 4.0 is a concept for the development of quality management processes based on the introduction of modern information technologies into traditional processes of quality management systems. Quality 4.0 is one of the components of the Fourth Industrial Revolution - Industry 4.0 [34].

The Quality 4.0 software model can be used to apply digital technologies to modernize traditional port management or communication processes.

Figure 2: Concept of the software model Quality 4.0 [34]

Using the tools of the software model Quality 4.0 when applying the QFD method in the design of port activities will enable the company to focus on the most important characteristics of a new or existing service considering a separate technological operation in the port, ensuring the maximum competitiveness of the terminal.

The construction of a matrix diagram in the QFD method can be performed based on the use of modern information technologies and applications created based on port operating systems. Concerning automatic mailings of requests for the satisfaction of consumers of port services (ship owners, cargo owners), these mailings will greatly facilitate the process of analyzing the compliance of services with the requirements and allow you to choose the most suitable service provider as part of the implementation of investment development projects in the port, which will provide the most competitive service. The result of using the software model Quality 4.0 when applying the QFD method can be the creation of artificial intelligence that analyzes the port services market and determines the level of competitiveness of the port service at the current time.

The quality of services provided by the port will be assessed based on the indicators presented in Table 1. The presentation of the QFD method for assessing the competitiveness of seaport services is carried out using a matrix diagram (Figure 3) - House of Quality [35].

Concerning the seaport, the conceptual model of the House of Quality is as follows.

Table 1
Qualitative Indicators of the Seaport

Indicator	Name of Indicator
1	Vessel service speed
2	Quality of ship service
3	Loading and unloading speed
4	Reliability of loading and unloading operations
5	Rating of port services operators
6	Cargo safety
7	Service cost
8	Use of modern information technologies
9	Safety of navigation in the port area

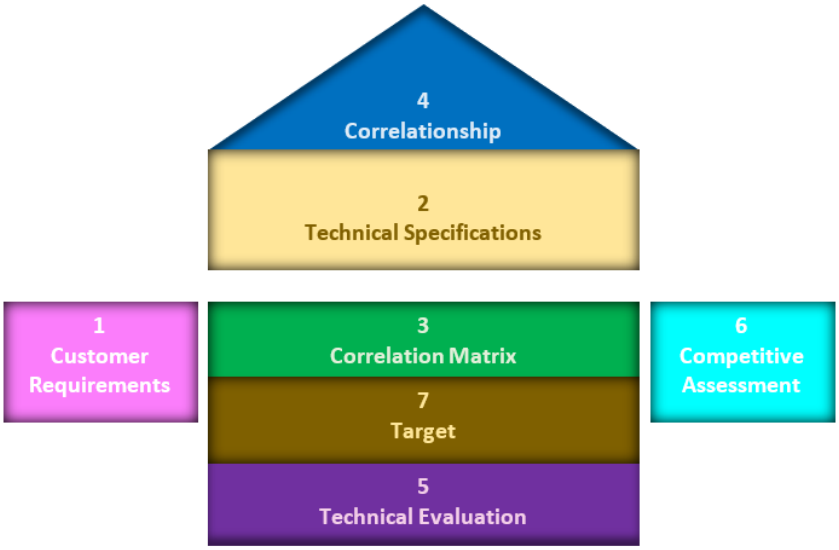

Figure 3: Software Model of the House of Quality in general form (1 - customer requirements, 2 - technical characteristics of the service, 3 - matrix of the relationship between customer requirements and technical characteristics of the service, 4 - correlation matrix of technical characteristics, 5 - the importance of technical characteristics, 6 - rating of importance for the consumer of each requirement and their weightiness, 7- targets)

Part (3) is the technical characteristics of the port services within the framework of investment development projects (2), and the rows correspond to the indicators of the competitiveness of port services (1). The table reflects the dependence of these data on each other. The roof of the house (4) is represented by information about the relationship between the technical characteristics of the port services. Part (1) includes port services competitiveness weightings, and the right room (6) includes an assessment of the quality of service provision in terms of competitiveness for the current service situation in the port. Part (5) contains the results of the analysis of the technical characteristics of the port services considering goals (7) provided by stakeholders, the target values of the technical characteristics, the assessment of the characteristics' importance. Information about port services provided by competing organizations can be obtained based on the Data Collection tool within the framework of the Quality 4.0 concept [36].

The tools of the software model Quality 4.0 will greatly simplify the collection of information for the implementation of the QFD method. Port service specifications are sufficiently obtained by automated data collection (Data Collection tool) or by accessing a global array of general port information as part of a port service specification study (Scalability tool). The tools Interaction, Analytics and Compliance will improve the reliability of the information received on the indicators of the competitiveness of port services. Consider the application of the QFD method based on the software model Quality 4.0 concerning a seaport (Figure 4).

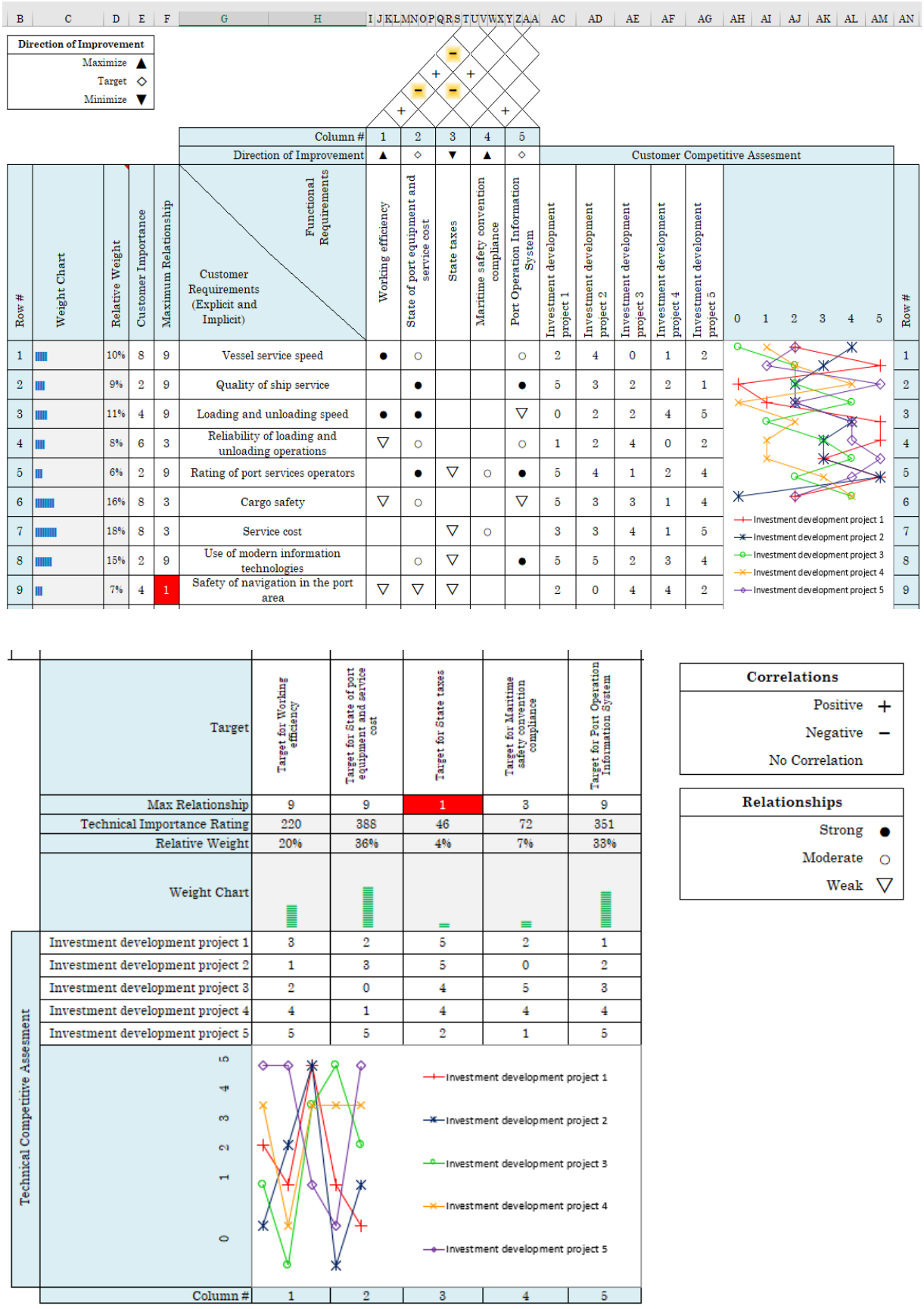

Figure 4: Software model of the information system for assessing the competitiveness of seaport services

The technical specification proposed in the research allows the development of an information system that could automatically calculate the competitiveness of port services.

The software model for assessing the competitiveness of seaport services based on the QFD method is as follows.

First, the qualitative indicators of the port operation are identified, forming the left room of the House of Quality model. Let's take a set of quality indicators as F, which forms a subset of m:

$$F = \{f_i\}, \left(i = \overline{1, m}\right), \quad (1)$$

where m is the total number of port performance indicators;

f_i is the i-th indicator of the port operation.

In the classic House of Quality model, significant indicators are identified through questioning potential consumers, surveys, and marketing research.

Further, the identified qualitative indicators of the port's performance are ranked by importance for each port investment development project (Figure 4).

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The technical characteristics of the port service are formed, which affect the implementation of consumer requirements. The characteristics of port services will be denoted by G, and:

$$G = \{g_j\}, \left(j = \overline{1, n}\right), \quad (2)$$

where n is the total number of technical characteristics of the port service;

g_j is the j-th characteristic of the port service within the framework of the investment development project.

In this case, as technical characteristics of port services, we consider labor productivity, the condition of transshipment equipment, port service fees, government taxes, the level of compliance with maritime conventions on maritime security, and the availability of an effective information system that ensures the implementation of port operations.

The weighting characteristics of the importance of the characteristics of port services form a subset of power m, and:

$$S = \{s_i\}, \left(i = \overline{1, m}\right), \quad (3)$$

where s_i is the weight characteristic of the i-th indicator of the port operation, which together with f_i forms an ordered pair $\{f_i; s_i\}$.

The right room contains assessments of the compliance of the investment development project with the quality of the services provided by the port (Figure 4). Let D be an indicator of the quality of the port service provided in terms of the implementation of a certain investment development project relative to the best and worst options for providing the same port service in other port investment development projects. They form a subset of power m:

$$D = \{d_i\}, \left(i = \overline{1, m}\right), \quad (4)$$

where d_i is the assessment of the implementation of the i-th port performance indicator, which, together with f_i, forms an ordered pair $\{f_i; d_i\}$.

The central part of the House of Quality model is filled in. Matrix V ($V = \|v_{ij}\|$) of the mutual influence of the characteristics of the port services and the properties of the port investment development project is filled in as follows: strong relationship, medium relationship, weak relationship, no connection.

The roof of the House of Quality model is being built. A triangular matrix V_G of the relationship of port service characteristics is formed (Figure 4). The principle of constructing correlation matrices is as follows: a positive relationship is denoted by "+"; a negative relationship is "-".

The complexity of the provision of services by the port as part of the implementation of a specific investment development project is assessed (on a five-point scale, where 1 - easy to implement, 5 - difficult to implement).

The indicator for evaluating the work of the port during the implementation of the investment development project in comparison with the qualitative indicators of the work of the port as a part of

the implementation of a similar investment development project forms a subset with a capacity of n, and:

$$C = \{c_j\}, (j = \overline{1, n}), \quad (5)$$

where c_j is the quality assessment of providing the j-th port service as a part of the implementation of the investment development project, which, together with g_j, forms an ordered pair $\{g_j; c_j\}$.

The weighting indicators of the complexity of providing port services, taking into account the performance of the port, form a subset of power n, and:

$$U = \{u_j\}, (j = \overline{1, n}), \quad (6)$$

where u_j is the weight indicator of the provision of the j-th port service within the framework of the investment development project, which, together with g_j, forms an ordered pair $\{g_j; u_j\}$.

Further, the direction of increasing the competitiveness of port services is determined after analyzing the House of Quality model considering the characteristics of the services provided as part of the selection of an investment project for the development of the port (Figure 4).

To identify the importance of port performance indicators in the framework of the implementation of the investment development project using the Quality 4.0 software model of the developed information system, a Pareto analysis was carried out based on the results of processing (Figure 5). The data for constructing the Pareto chart is given in Table 2.

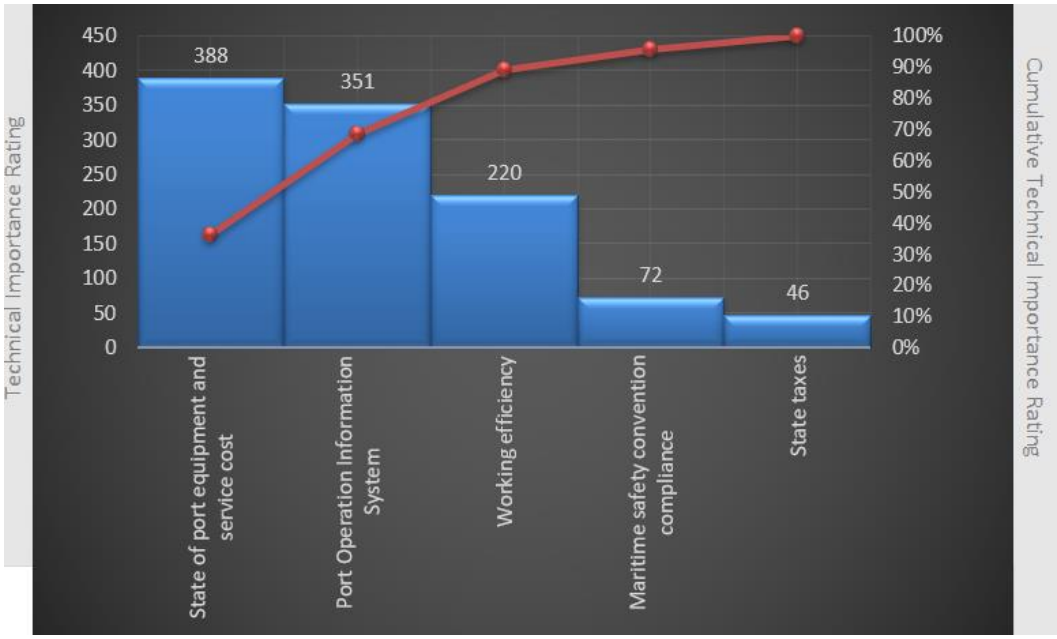

Figure 5: Pareto Chart

Table 2

Data for constructing the Pareto chart

Indicator	Name of Indicator	Technical Importance Rating
1	Working efficiency	220
2	State of port equipment and service cost	388
3	State taxes	46
4	Maritime safety convention compliance	72
5	Port Operation Information System	351

It follows from the analysis that the competitiveness of the services provided by the port is largely affected by indicators of the state of port equipment, the cost of port services, as well as the availability and effective functioning of the port operating information system.

To select an investment development project to be implemented in the port, we propose a mechanism for analyzing the impact of changes in port performance indicators, reflecting the general

properties of the services provided, on a comprehensive indicator of the quality of port services and allowing us to quantify the deviation of the properties of the selected investment development project from similar projects, taking into account the links both between and within the various components of the House of Quality model.

Let Z_i^{max} – the target value of the i-th indicator of the port (i = 1; m), corresponding to the i-th indicator of the project, which corresponds to the highest score value;

H_j^{max} –the target value of the j-th port service implementation considering the investment development project (j = 1; n) corresponding to the j-th port service implementation which corresponds to the highest score value;

Z_i – assessment of the i-th indicator of the port, corresponding to the investment development project being implemented, and set on a point scale;

H_j – assessment of the implementation of the j-th port service, corresponding to the investment development project being implemented and set on a point scale.

Based on the Euclidean metric, we will determine the metric characteristic of the port performance indicators for each of the investment development projects submitted for implementation, the achievement of which will make it possible to increase the competitiveness of the terminal:

$$\Delta Z = \sqrt{\sum_{i=1}^{m}(Z_i^{max} - Z_i)^2}. \quad (7)$$

Similarly, we calculate for each project the metric characteristic of the difference in the provision of port services depending on the selected project:

$$\Delta H = \sqrt{\sum_{j=1}^{n}\left(H_j^{max} - H_j\right)^2}. \quad (8)$$

Next, we calculate a comprehensive indicator of the port, the achievement of which will allow, based on the introduction of a modern information system, to choose an investment development project that will increase the competitiveness of the seaport:

$$\Delta K = \sqrt{\Delta Z^2 + \Delta H^2}. \quad (9)$$

The calculation results are presented in Figure 6.

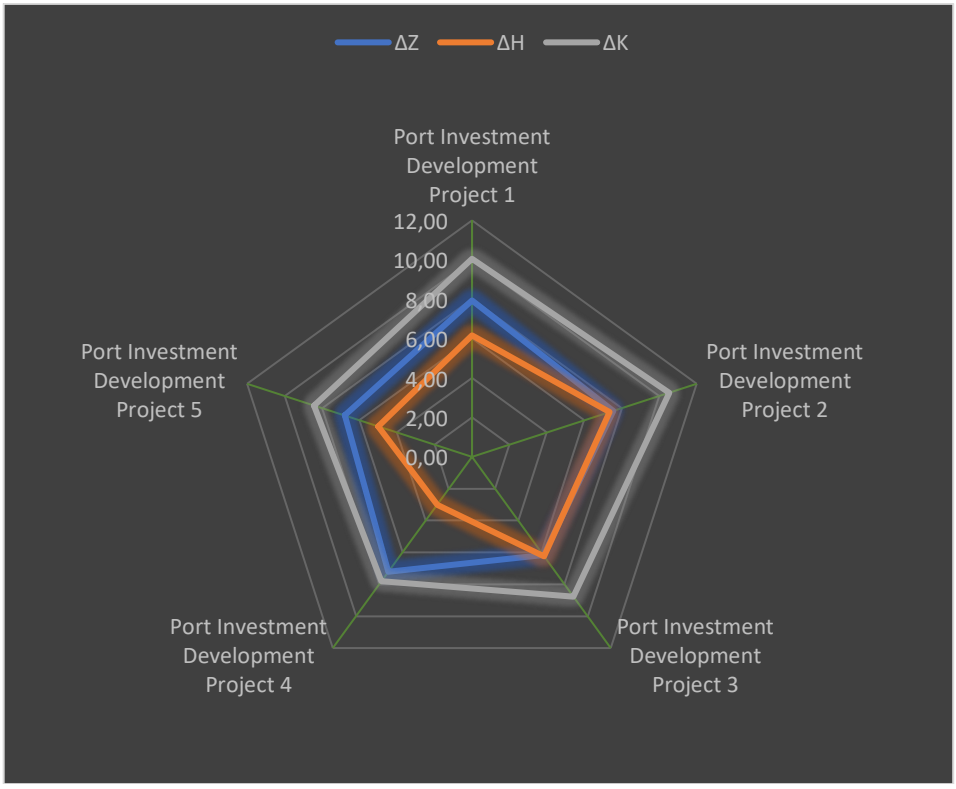

Figure 6: Model for assessing the integrated indicator of port performance in the context of using the Quality 4.0 software model

Based on the results obtained, it can be concluded that to maximize the competitiveness of the seaport, Port Investment Development Project 2 should be selected for implementation, which will improve the quality of port services provided as part of the use of the developed information system based on the proposed technical specification implemented into the port's operations taking into account the automated mode of calculating the port's competitiveness.

5. Conclusions

To assess the competitiveness of the port in investment development projects, the article proposed to use the Quality 4.0 software model, which is the basis for the development of quality management processes based on the introduction of modern information technologies into the traditional processes of port quality management systems.

Concerning the port, it is proposed to use the QFD method as a simulation of the actions of enterprises providing services in the seaport to turn emerging consumer requests (cargo owners, shipowners) regarding the quality of services into technical requirements for them, processes and equipment operating in the port. The implementation of the QFD method is more efficient when introducing innovative digital technologies into the management of the seaport.

This research based on the use of the information technology approach, made it possible to determine the directions for increasing the competitiveness of port services after analyzing the House of Quality model considering the characteristics of the services provided as part of the selection of an investment project development of the port.

Based on the construction of the House of Quality it was established that the competitiveness of services provided by the port is largely affected by indicators of the state of port equipment, the cost of port services, as well as the availability and effective functioning of the port operating information system.

Based on the calculation of a comprehensive indicator of port performance using information technology, a model has been developed for determining the most significant indicators that allow choosing an investment development project that will increase the competitiveness of the seaport.

The proposed technical specification allows the development of an information system that can automatically calculate the competitiveness of port services in the Quality 4.0 software model.

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