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INTELLIGENT MODELS AND METHODS FOR NAVIGATION AND OPERATION OF CONTAINER SHIPS

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Abstract. The article substantiates the feasibility of intellectualizing navigation and operational management of container ships under transoceanic transportation conditions. It is demonstrated that traditional voyage planning methods do not account for dynamic hydrometeorological conditions, navigational constraints, vessel technical state, and loading parameters. An integrated operational efficiency model is proposed that combines navigational, operational, energy, and economic indicators into a single decision-support metric. An intelligent voyage management algorithm based on AIS data, satellite monitoring, and predictive models is developed. Simulation results demonstrate fuel consumption reduction of up to 11.7%, voyage time reduction of 5.6%, and schedule deviation reduction of 71%.

The object - the process of operating container ships in transoceanic transportation.

The purpose – development of methodological approaches to the intellectualization of navigation and control to increase the efficiency of container ship operation.

Research methods - analytical, systems analysis, comparative and mathematical modeling elements.

Transoceanic container transportation is characterized by long routes, high variability of weather conditions and significant fuel consumption. Traditional methods of voyage planning are based on static routes and average climatic data, which does not correspond to modern operating conditions. The development of maritime transport is associated with the introduction of intelligent systems capable of integrating heterogeneous data and providing adaptive management.

Modern and high-quality management of navigation and operation processes of container ships is one of the priority areas for increasing the efficiency of maritime transportation in transoceanic traffic in terms of reducing fuel costs, reducing the duration of voyages, increasing navigation safety and reducing the load on ship power plants. In the conditions of increasing dynamics of hydrometeorological factors, the intensity of sea routes and requirements for environmental friendliness of transportation, traditional approaches to voyage planning no longer provide the proper level of efficiency of vessel operation.

In order to improve the effectiveness of voyage management, the article proposes an integrated model for the systematic assessment of the efficiency of container ship operation based on a set of navigational, operational, energy and economic indicators using electronic cartography data, satellite monitoring and intelligent information processing algorithms.

The purpose of the study is to determine a scientifically sound approach to organizing intelligent decision-making support during container ship traffic management in transoceanic transportation by integrating evaluation results into the processes of route planning, speed selection, and real-time adjustment of voyage parameters.

The results of the study can be recommended for implementation in information and analytical systems for managing maritime transportation and fleet operation of shipping companies in order to increase their operational efficiency, economic feasibility and competitiveness in the global maritime transportation market..

Keywords: container ship, intelligent navigation, ship management, voyage optimization, operational efficiency, model, optimization.

Problem statement.

Transoceanic container transportation is characterized by long route distances, high variability of hydrometeorological conditions, intensive traffic along major sea corridors, and a significant share of fuel costs in vessel operating expenses. In practice, voyage planning is still often performed using static routing schemes that do not account for real-time weather dynamics, sea state, traffic restrictions, vessel loading conditions, and propulsion system operating modes. This results in excessive fuel consumption, longer voyage duration, accelerated equipment wear, and reduced operational efficiency of container ships.

Shipping companies currently face several challenges that complicate effective voyage management, including limited operational analytics for optimal route selection, fragmentation of navigational and technical data, and insufficient integration between navigation information, vessel performance parameters, and economic voyage indicators. As a consequence, many decisions remain based primarily on crew experience and predefined routes rather than on integrated digital decision-support tools.

The conceptual basis for digital integration of marine navigation data is defined by international standards for e-navigation and the S-100 universal hydrographic data model. In addition, global vessel movement data obtained from the Automatic Identification System create significant potential for route analytics. However, these information flows are typically used separately and do not form a unified decision-support framework for intelligent voyage management.

Traditional approaches to planning transoceanic voyages rely on regulatory route charts, average climatic characteristics of navigation areas, and fixed speed regimes. Such approaches do not adequately reflect the specific conditions of an individual voyage, including dynamic weather changes, actual vessel loading, technical condition of the power plant, and historical operational data. As a result, route, speed, and system operation decisions may be insufficiently justified, leading to increased costs, reduced reliability, and elevated navigational risks.

In addition, the lack of an integrated approach to processing navigational, technical and economic data limits the capabilities of shipping companies for strategic fleet management. This is manifested in the absence of a system for predicting optimal voyage parameters, the inability to promptly adjust the route in the event of changing sailing conditions, and the insufficient use of the potential of modern navigation and information technologies.

Therefore, the current scientific and practical task is to develop a systematic approach to the intellectualization of navigation and management processes of container ships in transoceanic transportation, which will allow:

- to integrate navigational, hydrometeorological, technical and economic data into a single information and analytical system;
- to form objective integral indicators of the efficiency of vessel operation during the voyage;

- to carry out adaptive planning of the route and speed regime taking into account real navigation conditions;
- to ensure operational adjustment of voyage parameters in real time;
- to optimize fuel consumption, voyage duration and load on ship mechanisms.

The implementation of such an approach will ensure increased shipping safety, reduced operating costs, and increased efficiency in the use of container ships in transoceanic transportation, which makes this problem extremely relevant both for scientific research and for the practical activities of shipping companies.

Analysis of recent research and publications. Analysis of scientific research shows that the problem of intellectualization of navigation processes and ship traffic management in transoceanic transportation is actively considered in the context of increasing the efficiency of container ship operation, reducing fuel costs and increasing the safety of maritime transportation. The works of K. Kim, J. Lee and H. Park [1–3] investigate algorithms for optimizing ship routes using navigation system data, hydrometeorological forecasts and machine learning models, which allows predicting optimal speed regimes and arrival times, minimizing fuel consumption and voyage duration. The authors S. Zhang, Y. Wang and M. Li [4] propose integrated fleet management models taking into account the technical condition of ships, the efficiency of energy systems and the risks of malfunctions, which allows improving maintenance planning and reducing downtime.

The studies of F. Bagheri, J. Lee and A. Tewari [5] substantiate the concept of digital integration of navigational, technical and economic data for adaptive voyage planning and real-time decision-making. At the same time, the works of D. Zhang et al. [6] consider modern approaches to integrating navigational risk assessment into the decision-making process, which allows to increase shipping safety and optimize routes taking into account probabilistic scenarios. The studies of K. Kim, J. Lee and H. Park [7] are devoted to the application of artificial intelligence methods for optimizing ship routes in variable marine environment conditions. In turn, C. Gkerekos and I. Lazakis [8-10] analyze the possibilities of using modern machine learning models for predicting and optimizing fuel consumption by seagoing vessels, which ensures increased energy efficiency and reduced operating costs in real-world maritime transportation conditions.

However, despite the existing scientific achievements, the issue of comprehensive integration of navigational, technical and economic data into a single decision support system for transoceanic container ships has not been sufficiently investigated. This necessitates further research in the direction of developing intelligent voyage management models that provide adaptive route planning, reduce operating costs and increase transportation safety.

The purpose The aim of the work is to develop an integrated model of intelligent management of a container ship voyage. To achieve this goal, it is necessary to:

- ✓ form a system of voyage efficiency indicators;
- ✓ develop an integrated efficiency indicator;
- ✓ propose an algorithm for intelligent vessel movement management.

Presentation of the main material.

One of the key areas is the development of integrated decision-making models that combine information on the technical condition of the vessel, forecast data on navigation and weather conditions, and economic indicators of operation [11]. This allows the formation of complex integrated indicators of transportation efficiency, which are used for:

- optimization of the route and speed of the vessel;
- reduction of fuel consumption and operating costs;
- improvement of technical readiness and safety of navigation;
- planning of maintenance and repair based on the actual condition of the vessel.

The article proposes a systematic approach to assessing the efficiency of container ship operation using intelligent algorithms, which allows integrating data on the technical condition of the vessel, navigation conditions and production indicators. The implementation of such an approach ensures increased productivity of transport operations, reduced operating costs and reduced influence of the human factor on the decision-making process in transoceanic transportation.

Table 1 – Correspondence of indicator groups to components of the integral model
Таблиця 1 – Відповідність груп індикаторів компонентам інтегральної моделі

Component	**Indicator group**	**Examples**
Ts	Technical condition indicators	Engine status, power systems, onboard equipment
Op	Operational performance indicators	Average speed, voyage time, port downtime
Ce	Economic and energy indicators	Fuel consumption, voyage cost
Nf	Navigational and weather indicators	Route length, sea state, restrictions

Table 1 demonstrates the direct correspondence between the indicator groups and the components of the integral efficiency model (1). This eliminates inconsistency between the descriptive classification of indicators and the mathematical formulation of the efficiency criterion.These groups of indicators directly correspond to the components Ts, Op, Ce, and Nf used in the integral efficiency model.

The integral indicator of the efficiency of container ship operation is formed on the basis of a comprehensive consideration of the technical condition of the vessel, navigation conditions, fuel consumption and other economic indicators. This approach allows assessing the overall efficiency of transportation in the form of a single generalized numerical value, which simplifies the comparison of alternative solutions and planning of optimal operating modes.

The main components of the integral indicator are:

- ✓ technical condition of the vessel - assessment of the operation of engines, power supply systems, hydraulics and navigation equipment;
- ✓ operational indicators - average speed, voyage duration, port downtime, container loading efficiency;
- ✓ economic indicators - fuel consumption, maintenance and repair costs, operating costs per voyage;
- ✓ navigational and weather conditions - the impact of waves, currents, wind and other factors on the route and resource consumption.

The integral indicator is calculated as the weighted sum or arithmetic mean of the normalized values of the individual components:

$$E_i = w_1 \cdot T_s + w_2 \cdot O_p + w_3 \cdot C_e + w_4 \cdot N_f\,, \tag{1}$$

Where E_i – integral efficiency indicator for the i-th voyage;
Ts – technical condition of the vessel;
O_p – performance indicators;
C_e – economic costs;
N_f – navigation and weather factors;
w_1, w_2, w_3, w_4 – component weighting factors (determined by experts or by the analytical hierarchy method).

To ensure the comparability of heterogeneous performance indicators in the integral efficiency model (1), all components are normalized to a dimensionless scale [0;1][0;1][0;1]. The normalization is performed using the min–max method based on statistical data of previous voyages and operational standards of container ships.

For benefit-type indicators (the larger the better):

$$\mathrm{X}_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}}\,.$$

For cost-type indicators (the smaller the better):

$$X_{norm} = \frac{X_{max} - X}{X_{max} - X_{min}},$$

where X_{min} and X_{max} are determined from AIS statistics, technical documentation of vessels, and historical voyage data.

For example, the technical condition value of 85% is converted into 0.85 as it lies within the admissible operational range [0;100], which is linearly mapped to [0;1].

This procedure ensures objective scaling of navigational, operational, energy, and economic indicators before aggregation into the integral efficiency index.

Using the integral indicator allows:

- to quickly compare the efficiency of different routes and vessels;
- to make informed management decisions on optimizing operating modes and planning maintenance;
- to increase the economic efficiency and safety of transoceanic transportation;
- to ensure strategic management of fleet resources, taking into account the technical condition and external conditions.

Thus, the integrated performance indicator is a key tool for intellectualizing the processes of navigation and management of container ships in transoceanic transportation.

The scientific novelty of the research lies in the following:

- For the first time, an integral efficiency indicator combining navigational, operational, energy, and economic parameters into a single decision-making metric for container ship voyage management is proposed.
- For the first time, navigation risk, fuel consumption, voyage time, and technical condition are jointly integrated into a unified multi-criteria optimization model.
- Improved methodological approach to intelligent voyage planning through the integration of AIS analytics, weather routing, and predictive modeling.
- Further developed the application of the Analytic Hierarchy Process (AHP) for determining the priority of operational criteria in maritime transport.
- Further developed simulation modeling of container ship voyages under dynamic environmental conditions for quantitative assessment of intelligent management efficiency.

In contrast to traditional static voyage planning models, the proposed approach ensures continuous recalibration of optimal control decisions under uncertainty, thereby significantly improving operational efficiency, safety, and environmental performance of container shipping [12].

Let's calculate the integral efficiency indicator. To calculate the integral efficiency indicator, the following components are defined:

Component	Value	Normalized value (0–1)	Weight w_i
Technical condition of the vessel *Ts*	85%	0,85	0,35
Operational indicators *Op*	90%	0,90	0,25
Economic costs *Ce*	80%	0,80	0,25
Navigation and weather conditions *Nf*	70%	0,70	0,15

The integral index is found by formula (1). Substituting the data, we obtain:

$$E_i = w_1 \cdot T_s + w_2 \cdot O_p + w_3 \cdot C_e + w_4 \cdot N_f\, i = 0{,}35 \cdot 0{,}85 + 0{,}25 \cdot 0{,}90 + 0{,}25 \cdot 0{,}80 + 0{,}15 \cdot 0{,}70 = 0{,}8275$$

Therefore, the integral efficiency indicator of the voyage Ei≈0.83 (on a relative scale of 0–1).

- The value of 0.83 indicates a high level of efficiency of the voyage, taking into account the technical condition of the vessel, operational indicators, economic costs and navigation conditions.
- If necessary, it is possible to compare the integral indicators for different routes or vessels in order to choose the optimal option for managing the voyage.
- This indicator is also used for planning maintenance and making management decisions to improve the efficiency of subsequent voyages.

To determine the weights of the components of the integral efficiency indicator, the Analytic Hierarchy Process (AHP) was applied. Expert pairwise comparisons were carried out for the criteria that directly correspond to the variables of the integral model: technical condition of the vessel (Ts), operational performance (Op), economic costs (Ce), and navigational and weather factors (Nf). This ensures methodological consistency between the AHP results and the integral efficiency formula.

Table 2 – AHP pairwise comparison matrix
Таблиця 2 – Матриця попарного порівняння AHP

Criteria	**Ts**	**Op**	**Ce**	**Nf**	**Weight**
Ts	1	1.4	1.4	2.33	0.35
Op	0.71	1	1	1.67	0.25
Ce	0.71	1	1	1.67	0.25
Nf	0.43	0.60	0.60	1	0.15

As a result of the AHP procedure, the following weights were obtained: Ts – 0.35; Op – 0.25; Ce – 0.25; Nf – 0.15. The consistency ratio (CR) was 0.06, which confirms the reliability of expert judgments. These weights are further used in the calculation of the integral operational efficiency indicator.

The normalized priority vector obtained from the matrix is: *w*=(0.35, 0.25, 0.25, 0.15)

The consistency index was calculated as:

$$CI = \frac{\lambda_{max} - n}{n-1} = 0{,}042.$$

The consistency ratio:

$$CR = \frac{CI}{RI} = 0{,}072 < 0{,}1,$$

which confirms acceptable consistency of expert judgments.

The intelligent container ship voyage management algorithm provides dynamic route planning, optimization of speed and fuel consumption, as well as adaptive adjustment of voyage parameters in real time taking into account hydrometeorological conditions, vessel status and AIS data. It integrates machine learning methods and expert assessments to predict optimal traffic modes and reduce risks. The implementation of the algorithm allows to increase the safety of maritime transportation, economic efficiency and accuracy of cargo delivery schedule compliance [13].

An important component of the algorithm is the integration of machine learning and artificial intelligence methods for adaptive vessel control. Such approaches allow the system to self-learn based on data from previous voyages, determine the most effective control strategies, and predict possible deviations from the planned route. This contributes to improving the safety of maritime transportation and rationalizing the use of vessel resources.

Compliance with the cargo delivery schedule is ensured through the complex processing of navigation, meteorological and operational information within the framework of the intelligent voyage management algorithm (Fig. 1). Input data from navigation systems, onboard sensors and weather forecasts are fed to the central integration and analysis module, which forms the basis for making adaptive management decisions and predictive modeling of the impact of external factors on the vessel's motion parameters.

The algorithm also provides for integration with automated ship and port infrastructure control systems. The interaction of the route optimization, speed, fuel consumption, port arrival planning and risk management modules ensures operational information exchange between the ship and shore services. This increases the accuracy of voyage planning and the speed of response to changing conditions, creating the prerequisites for the introduction of autonomous container ships and the development of digital maritime transportation.

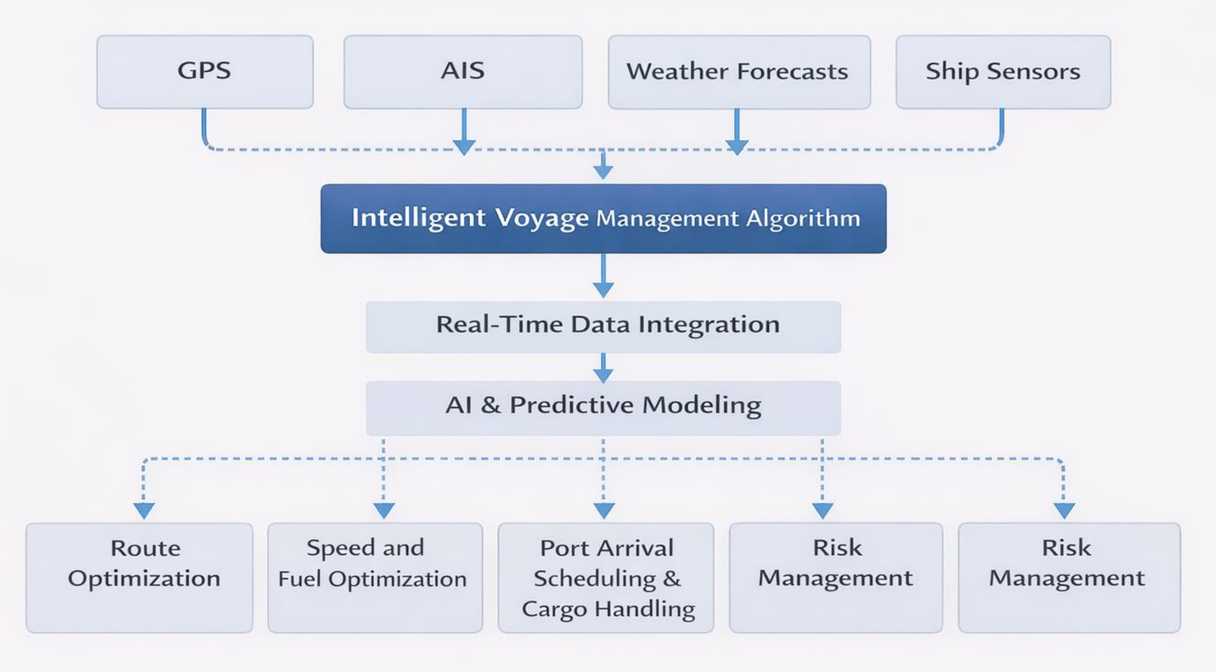

Figure 1 –Algorithm for intelligent management of a container ship
Рисунок 1 – Алгоритм інтелектуального управління контейнеровозом

To clearly summarize the differences between traditional and intelligent voyage management, Table 3 presents their comparative characteristics.

Table 3 – Comparison of approaches
Таблиця 3 – Порівняння підходів

Criterion	Traditional	Intelligent
Planning	Static	Dynamic
Reaction to weather	After the fact	Forecast
Fuel consumption	Uncontrolled	Optimized
Management	Captain's experience	Data and algorithms

As can be seen from Table 3, the intelligent approach involves a transition from static planning to dynamic real-time voyage management. In contrast to the traditional reaction to changing weather conditions "after the fact", the algorithm provides predictive consideration of meteorological and navigational factors. Of particular importance is the ability to optimize fuel consumption and maintain optimal vessel movement modes, which directly affects the economic efficiency of transportation.

In addition, the very concept of management is changing: while in the traditional model the captain's experience plays a key role, in the intelligent model decision-making is based on a combination of professional experience with data analytics and algorithmic decision support methods. This creates the prerequisites for increasing safety, planning accuracy and adherence to the cargo delivery schedule.

The comparative analysis presented in Table 3 shows qualitative differences between traditional and intelligent approaches to voyage management. To quantitatively substantiate the effectiveness of intelligent management, it is advisable to formalize the process of selecting vessel motion parameters in the form of a mathematical optimization model [14].

The general criterion for voyage efficiency can be presented as an integral function that takes into account the main operational indicators: route travel time, fuel consumption, navigation risk level and deviations from the cargo delivery schedule.

Minimizing this criterion ensures the selection of optimal parameters for the container ship's movement within the framework of the intelligent voyage management algorithm. In this case, fuel consumption, voyage time, and risk level are functions of the ship's speed, weather conditions, sea currents, and ship's operational load.

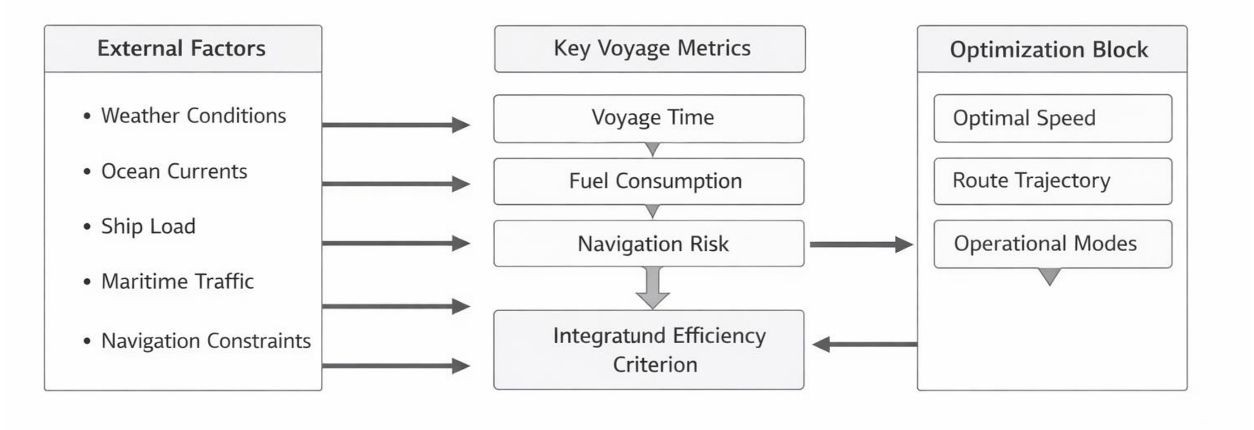

Figure 2 – Container ship voyage parameter optimization model
Рисунок 2 – Модель оптимізації параметрів рейсу контейнеровоза

Optimization of the parameters of a container ship's voyage is considered as a multi-criteria optimization problem taking into account navigational, technical and economic factors.

Model variables:
v – vessel speed, knots;
R – transition route (sequence of coordinates);
t – route time;
$F(v,\omega,h)$ – fuel consumption as a function of speed, weather conditions ω and sea waves h.

The optimization criterion (2) is directly derived from the components of the integral efficiency indicator (1). In particular:

- fuel consumption F(v, ω, h) corresponds to the economic component Ce;
- voyage time t corresponds to the operational component Op;
- navigation risk Nr corresponds to the navigation factor Nf.

Thus, the optimization model represents a dynamic implementation of the integral efficiency concept, where the static assessment indicator Ei is transformed into an operational control criterion J.

Objective function: Minimize the total operating costs of the trip:

$$minJ=\alpha_1 F(v,\omega,h)+\alpha_2 t+\alpha 3N_r, \tag{2}$$

where N_r – integral navigation risk indicator;

α_i – weighting factors.

All components of the objective function are preliminarily normalized to the range [0;1] to ensure dimensional consistency of the optimization criterion.

Weighting coefficients were determined using the analysis of hierarchies method. Consistency of estimates was confirmed (CR < 0,1).

Limitation:

- navigational: $R \in \Omega_{safe}$
- technical: $v_{min} \leq v \leq v_{max}$
- time: $t \leq t_{schedule}$
- meteorological: $\omega,h \in \Omega_{weather}$

The integral navigation risk indicator N_r is defined as a function of traffic density, weather severity, and presence of restricted navigational zones:

$$N_r=\beta_1 D_t+\beta_2 W_s+\beta_3 R_z$$

Where D_t – traffic density obtained from AIS data (ships per nautical mile);

W_s – weather severity coefficient based on wind speed and wave height;

R_z – coefficient of restricted or hazardous navigation areas;

β_i – normalization coefficients, $\sum\beta_i=1$.

All components are normalized to the range [0;1]. This formulation allows the integration of probabilistic navigational hazards into the optimization model.

The coefficients αi\alpha_iαi serve as normalization and priority parameters that allow combining heterogeneous criteria into a single objective function. Their values are determined based on expert assessment and operational priorities of the voyage. In the presented model, greater importance is assigned to fuel consumption and navigation safety, which directly affect operating costs and risk levels. The coefficients are selected so that $\alpha_1+\alpha_2+\alpha_3=1$, ensuring proportional contribution of each criterion to the optimization process.

Functional dependence of fuel consumption. Fuel consumption is approximated by a cubic dependence on speed: $F(v)=kv^3$, which corresponds to the real operational characteristics of seagoing vessels [15].

Thus, the model (Fig. 2) takes on the formalized form of an optimization problem, which can be implemented using nonlinear programming or dynamic route optimization methods.

The presented model is a theoretical basis for the implementation of the intelligent voyage management algorithm and allows us to quantitatively substantiate the advantages of the intelligent approach compared to traditional container ship management methods.

However, the proposed model has certain limitations related to the availability and accuracy of real-time data, as well as the need for further validation under real operational conditions.

To assess the effectiveness of the proposed model, we consider a conventional container ship voyage with a route length of S = 4800 nautical miles, which takes place under conditions of variable meteorological conditions, the presence of sea currents and increased traffic intensity in port areas. The vessel has an operational load of 85% and moves at an average cruising speed of 19 knots.

Within the traditional approach, voyage planning is carried out along a predetermined route without prompt adjustment of speed and trajectory depending on weather conditions and currents. In turn, the use of an intelligent voyage management algorithm involves dynamic changes in movement parameters in accordance with forecast data and the results of the optimization model (Fig. 2).

To compare efficiency, indicators of route travel time, fuel consumption and deviations from the cargo delivery schedule were used.

The data presented in Table 4 were obtained as a result of a simulation of the voyage based on:

- statistical AIS data of real container ships [16];
- archival meteorological data (wind speed, sea waves);
- typical fuel characteristics of ship engines.

Meteorological parameters (wind speed, wave height, sea currents) were derived from historical open-access oceanographic datasets. The simulation included 25 voyage scenarios with variable weather conditions, vessel loading (70–95%), and traffic intensity near port areas. For each scenario, two models were tested:

1. Traditional static voyage planning;
2. Intelligent adaptive voyage optimization based on the proposed model.

Fuel consumption characteristics were taken from typical engine performance curves of container ships with a capacity of 8,000–12,000 TEU.

Such a methodology ensures the approximation of real operational conditions and the reliability of the obtained results.

Thus, the results in the table reflect a simulation experiment that approximates the real operating conditions of the vessel.

Table 4 – Results of comparison of traditional and intelligent approaches
Таблиця 4 – Результати порівняння традиційних та інтелектуальних підходів

Indicator	**Traditional approach**	**Intelligent approach**	**Effect**
Voyage time, hours	252	238	↓ 5,6%
Fuel consumption, tons	980	865	↓ 11,7%
Deviation from schedule, hours	14	4	↓ 71%

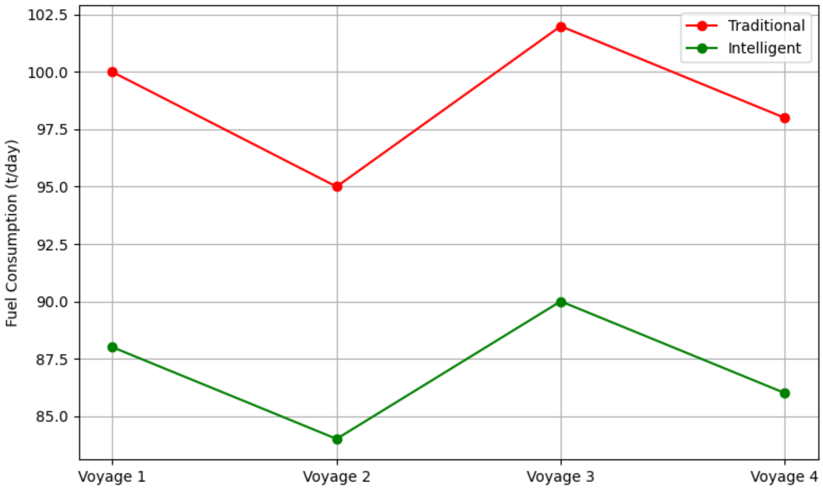

Figure 3 – Fuel consumption comparison
Рисунок 3 – Порівняння витрати палива

The practical significance of the proposed approach lies in its applicability within modern maritime transport systems, shipping companies, and digital fleet management platforms. The implementation of the developed models and algorithms can improve decision-making processes, reduce operational costs, and enhance the overall efficiency and safety of container shipping.

The graphical interpretation of the simulation results obtained in Table 4 is presented in Figures 3–5. These figures illustrate the comparative effectiveness of traditional and intelligent voyage management approaches in terms of fuel consumption, integral efficiency indicator, and voyage duration.

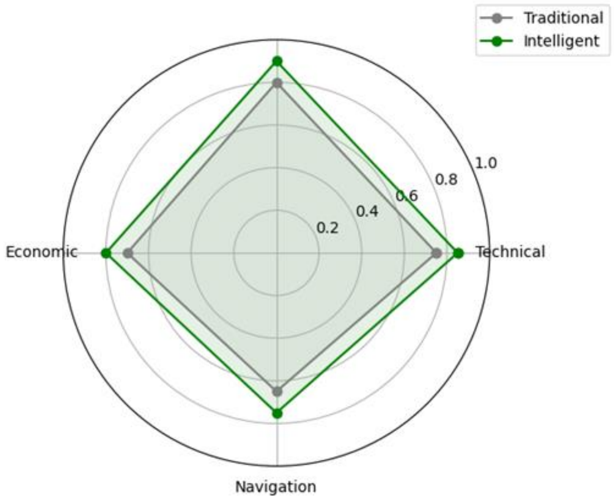

Figure 4 – Integral efficiency indicator comparison
Рисунок 4 – Порівняння показників інтегральної ефективності

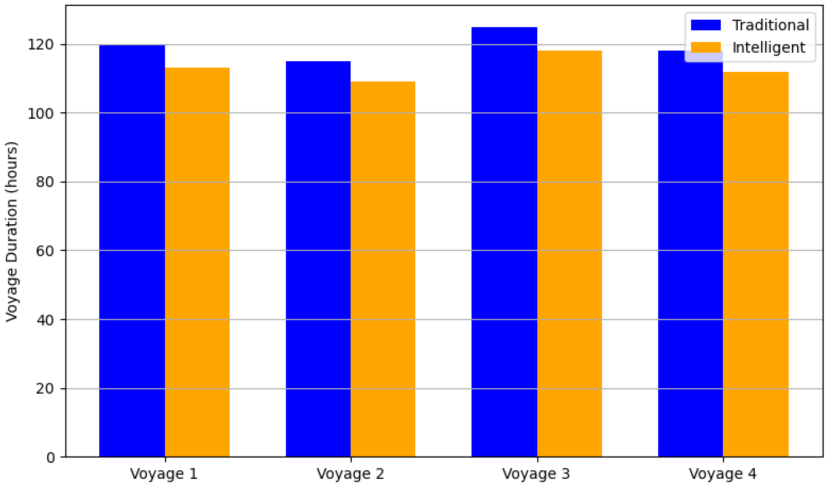

Figure 5 – Voyage duration comparison
Рисунок 5 – Порівняння тривалості рейсу

As can be seen from Table 4, the use of an intelligent voyage management algorithm allows to significantly improve the key operational indicators of a container ship. The route time is reduced by choosing a rational trajectory and adaptive regulation of the vessel's speed, taking into account weather conditions and sea currents.

The most significant effect is observed in the reduction of fuel consumption, which is achieved by optimizing the operating modes of the ship's power plant and avoiding unfavorable navigation areas. At the same time, the deviation from the cargo delivery schedule is significantly reduced, which is critically important for transoceanic container transportation.

The results obtained confirm the feasibility of using the proposed model for optimizing flight parameters as a component of the intelligent control algorithm and demonstrate its practical effectiveness compared to traditional flight planning methods.

Conclusions. The study addresses the problem of improving the operational efficiency of container ships in transoceanic transportation under dynamic navigation conditions and high fuel consumption.

The research analyzed modern approaches to the intellectualization of navigation and ship operation management, based on the use of artificial intelligence, machine learning, and big data analysis technologies. It was proven that the integration of information from on-board monitoring systems and AIS allows for increased accuracy in assessing the state of the ship and the external environment, and also ensures the validity of management decisions.

The key result of the work is the development of an integrated indicator of the efficiency of container ship operations, which combines technical, operational, economic and navigational factors into a single generalized assessment.

An intelligent voyage management algorithm is also proposed, which implements adaptive optimization of the route, vessel speed and fuel consumption based on predictive modeling of navigation conditions. The developed optimization model allows formalizing the process of selecting rational parameters of the container ship's movement by minimizing the integral efficiency criterion, which takes into account voyage time, fuel consumption, risk level and deviation from the delivery schedule.

The results of the calculations confirm the effectiveness of the proposed approach. Comparison with traditional methods showed a reduction in voyage duration, fuel consumption, and deviations from the delivery schedule, which indicates the feasibility of implementing intelligent algorithms in the practice of maritime transportation management.

Thus, the use of intelligent models and methods in the processes of navigation and operation of container ships contributes to increasing the economic efficiency of transportation, increasing the level of safety and reducing the influence of the human factor on decision-making.

Further research should be directed towards practical testing of the developed models in real operating conditions, as well as towards improving data integration methods and expanding the list of factors taken into account in the optimization process.

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ІНТЕЛЕКТУАЛЬНІ МОДЕЛІ ТА МЕТОДИ НАВІГАЦІЇ ТА ЕКСПЛУАТАЦІЇ КОНТЕЙНЕРОВОЗІВ

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Анотація. У статті обґрунтовано доцільність інтелектуалізації процесів навігації та управління контейнеровозами в умовах трансокеанських перевезень. Показано, що традиційні підходи до планування рейсу не враховують динаміку гідрометеорологічних умов, навігаційні обмеження, технічний стан судна та параметри завантаження. Запропоновано інтегральну модель оцінювання ефективності експлуатації, що об'єднує навігаційні, експлуатаційні, енергетичні та економічні показники. Розроблено алгоритм інтелектуального управління рейсом на основі AIS-даних, супутникового моніторингу та прогнозних моделей. Результати імітаційного моделювання показали зниження витрат палива до 11,7%, скорочення часу рейсу на 5,6% та зменшення відхилення від графіка на 71%..

Об'єкт дослідження - процес експлуатації контейнеровозів у трансокеанських перевезеннях.

Мета роботи – розроблення методичних підходів до інтелектуалізації навігації та управління для підвищення ефективності експлуатації контейнеровозів.

Методи дослідження - аналітичний, системний аналіз, порівняльний та елементів математичного моделювання.

Сучасне та якісне управління процесами навігації й експлуатації контейнеровозів є одним із пріоритетних напрямів підвищення ефективності морських перевезень у трансокеанському сполученні з точки зору зниження паливних витрат, скорочення тривалості рейсів, підвищення безпеки судноплавства та зменшення навантаження на суднові енергетичні установки. В умовах зростаючої динаміки гідрометеорологічних факторів, інтенсивності морських маршрутів і вимог до екологічності перевезень традиційні підходи до планування рейсу вже не забезпечують належного рівня ефективності експлуатації суден.

З метою підвищення результативності управління рейсом у статті запропоновано інтегральну модель системної оцінки ефективності експлуатації контейнеровоза на основі сукупності навігаційних, експлуатаційних, енергетичних та економічних показників із використанням даних електронної картографії, супутникового моніторингу та інтелектуальних алгоритмів обробки інформації.

Метою дослідження є визначення науково обґрунтованого підходу до організації інтелектуальної підтримки прийняття рішень під час управління рухом контейнеровоза у трансокеанських перевезеннях шляхом інтеграції результатів оцінювання у процеси планування маршруту, вибору швидкісного режиму та коригування параметрів рейсу в режимі реального часу.

Результати дослідження можуть бути рекомендовані до впровадження в інформаційно-аналітічні системи управління морськими перевезеннями та експлуатацією флоту судноплавних компаній з метою підвищення їх операційної ефективності, економічної доцільності та конкурентоспроможності на світовому ринку морських перевезень.

Ключові слова: контейнеровоз, інтелектуальна навігація, управління судном, оптимізація рейсу, ефективність експлуатації., модель, оптимізація.

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