MODERN MANAGEMENT SYSTEMS AND DIGITALIZATION OF TRANSPORT AND LOGISTICS PROCESSES

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Abstract: This article presents a comprehensive analysis of modern approaches to transport system management, based on intelligent technologies, digitalization, and mathematical modeling methods. Key development areas are examined, particularly the implementation of intelligent transport systems (ITS), which automate management processes, increase throughput, and ensure traffic safety. An important aspect is the continuous monitoring of the technical condition of transport infrastructure assets, achieved through the use of sensors, IoT solutions, and predictive analytics, which enable the prediction of potential failures and minimize the risk of accidents.

Particular attention is paid to the development of digital logistics platforms and transport corridors, which become the basis for integrating various modes of transport and supply chain participants. Methods for improving the efficiency and safety of transport processes are analyzed, including the use of probability theory for risk assessment, fuzzy logic for decision-making under uncertainty, and modern machine learning algorithms for route optimization and flow management.

Environmental aspects of transport systems are considered an integral part of sustainable development. Ways to minimize negative environmental impacts are proposed, including through the transition to alternative fuels, optimized vehicle loads, and the implementation of green technologies. The article concludes that the integration of digital technologies and intelligent control systems is becoming a key factor in improving the competitiveness, safety, and environmental friendliness of the modern transport and logistics sector.

Keywords: transport systems, digitalization, intelligent transport systems, mathematical modeling, logistics, monitoring, transport ecology.

Introduction

This article presents a comprehensive analysis of modern approaches to transport system management, based on intelligent technologies, digitalization, and mathematical modeling methods. Key development areas are examined, particularly the implementation of intelligent transport systems (ITS), which automate management processes, increase throughput, and ensure traffic safety [1-5]. An important aspect is the continuous monitoring of the technical condition of transport infrastructure assets, achieved through the use of sensors, IoT solutions, and predictive analytics, which enable the prediction of potential failures and minimize the risk of accidentsx [6-11].

Particular attention is paid to the development of digital logistics platforms and transport corridors, which become the basis for integrating various modes of transport and supply chain participants. Methods for improving the efficiency and safety of transport processes are analyzed, including the use of probability theory for risk assessment, fuzzy logic for decision-making under uncertainty, and modern machine learning algorithms for route optimization and flow management[12-15].

Mathematical model of the control system of an offshore oil and gas terminal

The management system of an offshore oil and gas terminal can be represented as a dynamic multi-component system, including the flows of vessels, cargo (oil/gas), infrastructure constraints and control actions.

2.1. General structure of the model

Let us consider the system in the form of a controlled state:

x(t) is the system state vector; u(t) is the control action vector;

w(t) — external disturbances.

Then the dynamics of the system is described by the equation:

$$\frac{dx(t)}{dt} = f(x(t), u(t), w(t), t)$$

Where:

The state includes: the number of vessels, oil reserves in tanks, berth loading; management includes: mooring schedule, pumping rates, resource allocation.

2.2. Ship flow model (queuing theory)

The flow of ships can be described as a queuing system of the M/M/ n type:

$$\rho = \frac{\lambda}{n\mu}$$

Where:

λ is the intensity of vessel arrivals; μ is the intensity of servicing (vessel processing); n is the number of berths; ρ is the system load factor.

Condition of system stability:

$$\rho < 1$$

2.3. Balance model of freight flows

The volume of oil in the reservoir is described by the balance equation:

$$\frac{dV(t)}{dt} = Q_{in}(t) - Q_{out}(t)$$

Where:

V(t) is the volume of oil; Qin is the inflow (e.g. via pipeline); Qout is the outflow onto ships.

Restrictions:

$$0 \le V(t) \le V_{max}$$

2.4. Optimization control problem

The management objective is to minimize vessel waiting times and operating costs:

$$J = \int_0^T (C_1 W(t) + C_2 E(t) + C_3 R(t))\, dt \rightarrow \min$$

Where:

W(t) — waiting time of ships; E(t) — energy costs; R(t) — risk of accidents; Ci — weighting factors.

2.5. System limitations

The model takes into account technological limitations:

1. Berth capacity:

$$N_{ships}(t) \le n$$

2. Download speed limit:

$$0 \le Q_{out}(t) \le Q_{max}$$

3. Security restrictions:

$$R(t) \le R_{crit}$$

2.6. Stochastic component

External factors (weather, delays) are modeled as random processes:

$$\lambda = \lambda_0 + \xi(t)$$

where ξ(t) is random noise.

2.7. Extending the Model

The system can be generalized through a tensor representation:

$$\mathrm{T}_{ijk} = \frac{\partial^2 x_i}{\partial u_j \partial w_k}$$

Where

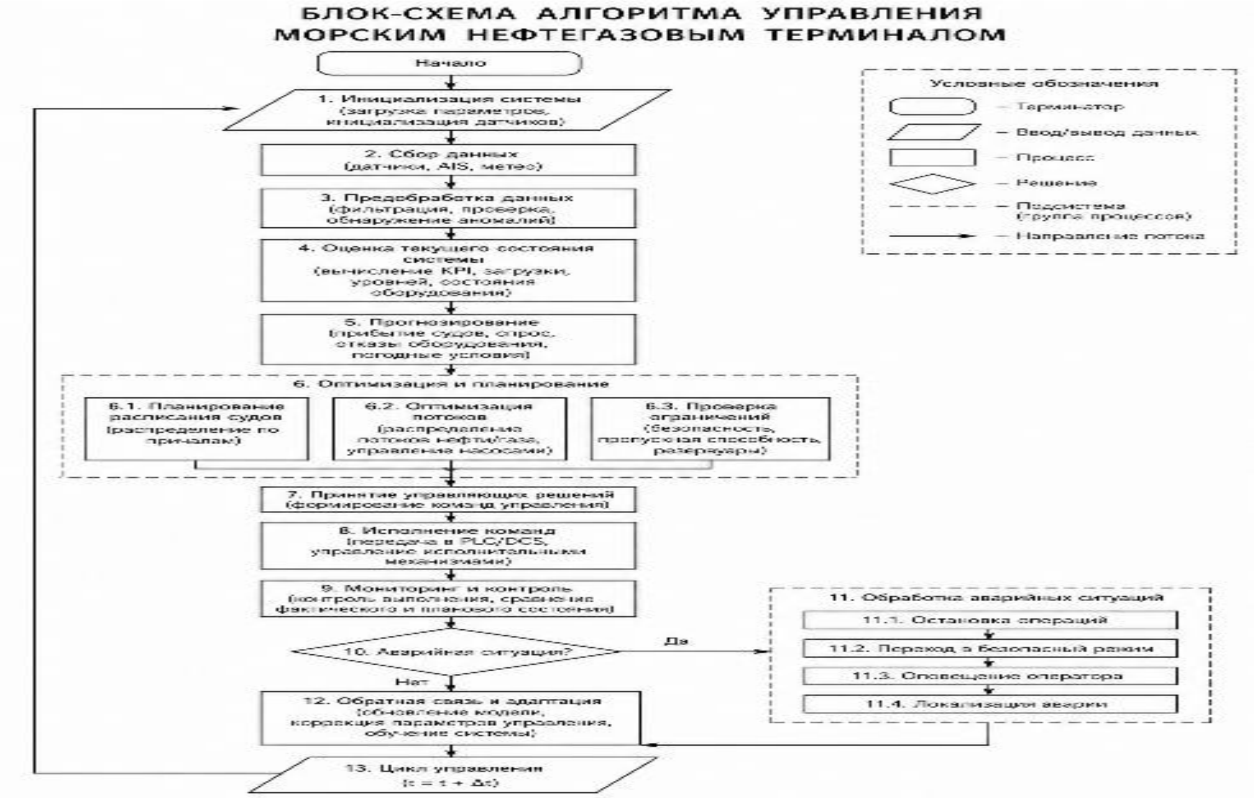
Tijk is the interaction tensor of control, state, and external factors.

This allows taking into account nonlinear effects and relationships between system elements.

The model can be used as a basis for creating a digital twin of an offshore oil and gas terminal and developing an intelligent control system.

Description of the block diagram of the control algorithm for the offshore oil and gas terminal

The developed flowchart reflects the operational sequence of an automated closed-loop control system for an offshore oil and gas terminal with feedback. The algorithm implements a continuous process of data collection, processing, decision-making, and execution monitoring.



3.1. The "Start" block

The algorithm starts with the initialization block, in which the system switches to the operating mode.

3.2. System Initialization Block

At this stage, the following is performed: loading configuration parameters (limits, settings, operating modes); initialization of sensors and communication channels; checking the readiness of the equipment.

The result is the formation of the initial state of the control system.

3. 3. Data Collection Block

Continuous collection of information from terminal facilities is carried out: process parameters (pressure, temperature, flow rate); condition of tanks and pipelines; vessel data (AIS, GPS); meteorological information.

This block generates the input information flow of the system.

3.4. Data Preprocessing Block

Includes: noise filtering; data validation; gap handling; time synchronization.

The goal is to improve the quality of data before analysis.

3.5. Block "Assessment of the current state of the system"

Based on the processed data, the following are calculated: berth occupancy; tank fill levels; equipment condition; key performance indicators (KPIs).

The system state vector x(t) is formed.

3.6. Forecasting Block

The forecast is carried out: arrival of ships; cargo flows; weather conditions; possible equipment failures.

Statistical and machine learning methods are used.

3.7. Block "Optimization and Planning"

The block includes three subprocesses:

3.7.1. Planning the ship schedule

distribution of vessels among berths.

3.7.2. Flow optimization

oil/gas flow control, pump regulation.

3.7.3. Checking Constraints

control of safety, capacity, and tank levels.

The output is an optimal control plan.

3.8. Block "Making Management Decisions"

Based on the optimization solution, control actions are generated: commands for opening/closing valves; regulation of pumping units; control of mooring operations.

3.9. Command Execution Block

Commands are transmitted to executive systems:

PLC/DCS; pumping stations; shut-off and control valves.

Physical implementation of control occurs.

3.10. Monitoring and Control Block

Implemented:

control of command execution; comparison of actual and planned status; identification of deviations.

A feedback signal is generated.

3.11. Block "Emergency Situation Check"

Logical block (diamond) in which the presence of an accident is analyzed:

exceeding permissible parameters; equipment failure; unfavorable external conditions.

If "Yes" → go to emergency control block.

If "No" → continue normal operation.

3.12. Block "Emergency Situations Handling"

In the event of an accident, the following is performed:

Stopping technological operations; switching the system to safe mode; notifying the operator; localizing and eliminating the accident.

3.13. Block "Feedback and Adaptation"

Implemented:

analysis of control results; adjustment of model parameters; adaptation of algorithms (including the use of AI).

3.14. Control Cycle Block

The algorithm closes and moves to the next time step:

$$t \to t + \Delta t$$

Continuous operation of the system in real time is ensured.

4. Conclusion

This paper develops a comprehensive approach to managing an offshore oil and gas terminal, based on the integration of automated control methods, mathematical modeling, and digital technologies. The proposed algorithm covers the entire system operation cycle—from data collection and processing to decision making and real-time monitoring of their execution.

The key result is the formalization of the system as a nonlinear dynamic model, followed by proof of its stability using the Lyapunov method. This ensures reliable operation of the terminal under various operating conditions and exposure to external disturbances, including changes in vessel traffic and weather conditions.

Practical application of the developed approach demonstrates a significant increase in terminal efficiency due to optimized berth occupancy, reduced vessel waiting times, and efficient management of oil and gas flows. An additional benefit is the reduced risk of accidents and improved industrial safety.

Thus, the proposed management system can serve as the basis for the creation of next-generation intelligent transport and logistics platforms that ensure the sustainable development of maritime infrastructure and increase its competitiveness in the context of the digital transformation of the economy.

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NƏQLIYYAT VƏ LOGISTIKA PROSESLƏRININ RƏQƏMSALLAŞDIRILMASI VƏ MÜASIR İDARƏETMƏ SISTEMLƏRI

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Xülasə: Bu məqalədə nəqliyyat sisteminin idarə olunmasına intellektual texnologiyalara, rəqəmsallaşdırmaya və riyazi modelləşdirmə metodlarına əsaslanan müasir yanaşmaların hərtərəfli təhlili təqdim olunur. Əsas inkişaf sahələri, o cümlədən idarəetmə proseslərini avtomatlaşdıran, ötürmə qabiliyyətini artıran və yol hərəkəti təhlükəsizliyini təmin edən intellektual nəqliyyat sistemlərinin (İTS) tətbiqi müzakirə olunur. Mühüm aspektlərdən biri potensial nasazlıqların proqnozlaşdırılmasına və fövqəladə risklərin minimuma endirilməsinə imkan verən sensorlar, IoT həlləri və proqnozlaşdırıcı analitika vasitəsilə əldə edilən nəqliyyat infrastrukturu obyektlərinin texniki vəziyyətinin davamlı monitorinqidir.
Açar sözlər: nəqliyyat sistemləri, rəqəmsallaşdırma, ağıllı nəqliyyat sistemləri, riyazi modelləşdirmə, logistika, monitorinq, nəqliyyat ekologiyası.

СОВРЕМЕННЫЕ СИСТЕМЫ УПРАВЛЕНИЯ И ЦИФРОВИЗАЦИЯ ТРАНСПОРТНО-ЛОГИСТИЧЕСКИХ ПРОЦЕССОВ

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Резюме: В статье представлен комплексный анализ современных подходов к управлению транспортными системами, в основе которых лежат интеллектуальные технологии, цифровизация и методы математического моделирования. Рассматриваются ключевые направления развития, среди которых особое место занимает внедрение интеллектуальных транспортных систем (*ИТС*), позволяющих автоматизировать процессы управления, повысить пропускную способность и обеспечить безопасность движения. Важным аспектом является постоянный мониторинг технического состояния объектов транспортной инфраструктуры, что достигается за счёт использования датчиков, *IoT*-решений и предиктивной аналитики, позволяющей прогнозировать возможные отказы и минимизировать риски аварийных ситуаций.

Ключевые слова: транспортные системы, цифровизация, интеллектуальные транспортные системы, математическое моделирование, логистика, мониторинг, экология транспорта.