



Parmen Khvedelidze
Elida Khvedelidze
George Gabedava

Integrated Maritime Transport Management Systems

From Mechanics to Logistics and Management

 **LAMBERT**
Academic Publishing

**Parmen Khvedelidze
Elida Khvedelidze
George Gabedava**

Integrated Maritime Transport Management Systems

FOR AUTHOR USE ONLY

FOR AUTHOR USE ONLY

**Parmen Khvedelidze
Elida Khvedelidze
George Gabedava**

Integrated Maritime Transport Management Systems

From Mechanics to Logistics and Management

FOR AUTHOR USE ONLY

LAP LAMBERT Academic Publishing

Imprint

Any brand names and product names mentioned in this book are subject to trademark, brand or patent protection and are trademarks or registered trademarks of their respective holders. The use of brand names, product names, common names, trade names, product descriptions etc. even without a particular marking in this work is in no way to be construed to mean that such names may be regarded as unrestricted in respect of trademark and brand protection legislation and could thus be used by anyone.

Cover image: www.ingimage.com

Publisher:

LAP LAMBERT Academic Publishing

is a trademark of

Dodo Books Indian Ocean Ltd. and OmniScriptum S.R.L publishing group

120 High Road, East Finchley, London, N2 9ED, United Kingdom

Str. Armeneasca 28/1, office 1, Chisinau MD-2012, Republic of Moldova,
Europe

Managing Directors: Ieva Konstantinova, Victoria Ursu

info@omniscryptum.com

Printed at: see last page

ISBN: 978-620-9-82841-6

Copyright © Parmen Khvedelidze, Elida Khvedelidze, George Gabedava

Copyright © 2026 Dodo Books Indian Ocean Ltd. and OmniScriptum S.R.L
publishing group

FOR AUTHOR USE ONLY



*Integrated Maritime Transport Management Systems:
From Mechanics to Logistics and Management*

*Batumi
2026*

Preface

Professors of Batumi Navigation University have worked in various fields of maritime development for years, studying issues of maritime transport movement and mechanisms of maritime transport, maritime management and the diversity of its directions, namely: management and organization of transportation of industrial and agricultural products; maritime relations at the state, regional and local self-government levels; maritime management and logistics; modern problems of maritime affairs, in particular, transport, and possible ways to solve them; features of the supply chain and logistics on the Black Sea coast of Georgia and in the Black Sea basin; maritime transport and communications management; and the introduction of IT technologies in maritime business, finance, transport and management, etc. Our work covers precisely these modern directions.

This work represents the faculty professors' recent efforts, grouped under one auspice: maritime affairs and navigation, industrial management issues, and transport and logistics.

Thus, we consider this collective monograph a summary of research conducted in recent years.

Parmen Khvedelidze

Master-Mariner, Doctor of Transport Sciences, Professor,
Rector at Batumi Navigation University

Elida Khvedelidze

Doctor of Medicine,
Associate Professor at Batumi Navigation University

George Gabedava

Doctor of BA (PhD),
Professor at Batumi Navigation University

Content

Elida Khvedelidze, Ekaterine Gvarishvili

THE PROBLEM OF OVERWEIGHT AND OBESITY AMONG GEORGIAN SAILORS.....5

Nino Tchilaia, Ekaterine Chikviani

THE IMPACT OF LOGISTICS ON BUSINESS PERFORMANCE.....10

Elida Khvedelidze, Ekaterine Gvarishvili

COMPARATIVE ANALYSIS OF HEALTHCARE MANAGEMENT SYSTEMS: EXPERIENCE OF GEORGIA AND NEIGHBOURING COUNTRIES.....21

Imeda Pakсадze, Iago Beridze, Givi Bakradze

DETERMINANTS OF STRUCTURAL CHANGE IN TRADE FLOWS.....51

Parmen Khvedelidze, Dursun Tsintsadze, Giorgi Kikvidze, Valerian Imnaishvili, Nino Beridze

MODERN NAVIGATION SYSTEMS AND THEIR ROLE IN INCREASING THE SAFETY OF MARINE TRANSPORTATION.....60

Levan Gvarishvili, Mirza Sugnishvili, Giorgi Abashidze

PROBLEMS OF RELATIONS WITH THE EURASIAN ECONOMIC UNION.....86

Tamar Diasamidze, Tatia Tsetskhladze

BUSINESS COMMUNICATIONS AS A FORMULA FOR EFFECTIVE BUSINESS RELATIONS.....93

Maia Chechelashvili, George Gabedava, Tengiz Aphkhazava; Nino Tchilaia

PROSPECTS FOR REALIZING THE POTENTIAL OF THE EURASIAN ECONOMIC UNION IN THE SYSTEM OF INTERNATIONAL TRANSPORT CORRIDORS.....100

Nugzar Bolkvadze, Ruslan Verdzadze, Aram Bazaian, Levan Bolkvadze, George Gabedava

OPTIMIZING THE OPERATION OF SHIPS WITH THE USE OF ARTIFICIAL INTELLIGENCE SYSTEMS.....107

<i>Kakhaber Khintibidze, Vladimir Nemsadze, Levan Gobadze, David Botsvadze</i>	
STRATEGIES OF ENHANCING THE ENERGY EFFICIENCY OF SHIPS WITHIN THE FRAMEWORK OF GLOBAL DECARBONISATION.....	127
<i>Teimuraz Gograchadze; Taniel Pakşadze</i>	
LOGISTICS AS A SCIENTIFIC TOOL FOR MANAGING FLOW PROCESSES.....	145
<i>Valerian Imnaishvili</i>	
ANALYSIS OF DEATH AND INJURY CASES AMONG GEORGIAN SEAFARERS: MEDICO-LEGAL ASSESSMENT AND RECOMMENDATIONS.....	150
<i>Valerian Imnaishvili, Giorgi Kikvidze</i>	
IMPROVING THE INTERACTION BETWEEN SEAPORTS AND RAIL TRANSPORT.....	155
<i>Parmen Kfvedelidze, Dursun Tsintsadze</i>	
STRATEGIES FOR ENHANCING THE COMPETITIVENESS AND ATTRACTIVENESS OF GEORGIA’S BLACK SEA PORTS.....	162
<i>George Gabedava, Nino Tchilaia</i>	
THE ROLE OF PPP FOR A TRANSITION TO GREEN PRACTICES IN THE MARITIME INDUSTRY.....	168
<i>Tamila Ardemanashvili</i>	
CARBON AND ITS IMPORTANCE.....	180

THE PROBLEM OF OVERWEIGHT AND OBESITY AMONG GEORGIAN SAILORS

Elida Khvedelidze

Associate Professor Batumi Navigation University

Ekaterine Gvarishvili

Associate Professor Batumi Navigation University

Abstract: Overweight and obesity are two of the major health problems worldwide. Today, it is also a pressing problem in the world's navies. A retrospective analysis was conducted to determine the prevalence of overweight among Georgian sailors.

450 sailors aged 20-60 who underwent medical professional examinations from 2021 to 2023 at the Batumi Seafarers' Medical Center were examined. Body mass index was calculated and compared across different age groups.

The normal weight of the examined seafarers was recorded in 9.5% of cases, overweight in 84.4%, and obesity in 6%. The overall prevalence of overweight and obesity was 90.5%. The overall average body mass index (BMI) was $26.9 \pm 0.5 \text{ kg/m}^2$. There was an age-dependent increase in BMI.

The study reveals a widespread prevalence of obesity among Georgian seafarers. It is necessary to continue research and implement measures to combat and prevent obesity.

Keywords: Obesity, body mass, economic impact

Introduction. Overweight and obesity are two of the major health problems worldwide. According to the World Health Organization, 2.8 million people die every year due to being overweight (World Health Organization, 2013). Obesity and overweight pose a serious health risk and lead to complex diseases such as ischemic cardiovascular disease, arterial hypertension, and type 2 diabetes mellitus (World Health Organization, 2013). Studies conducted by Bridger and Bennett indicate that body mass index (BMI) has a greater impact on high and effective work capacity than age (Bridger R.S, Bennett A.I., 2011).

Overweight is also a current problem in the world's navy today (Nittari G., Tomassoni D., Di Canio M., Traini E., Pirillo I., Minciocchi A., Amenta F., 2019). It poses not only a risk of harm to the health of the seafarer, but also a violation of the occupational safety of the crew (Bridger R.S, Bennett A.I., 2011). It is known that the rate of fatal accidents and injuries in the maritime transport sector is higher than in the construction and manufacturing industries (Roberts S.E., Nielsen D., Kotlowski A.,

Jaremin B., 2014). Due to the high risk of emergencies in the workplace, the duties and physical abilities of the seafarer must be proportional.

An overweight seafarer may not be allowed to work. Crewing and shipowner companies are increasingly turning to specialists to assess seafarers' health, noting that the rise in overweight seafarers has become not only a social but also an economic problem.

Today, several studies have examined the problems of overweight and obesity among seafarers (Hansen H.L., Hjarnoe L., Jepsen J.R., 2011). The main goal of these studies is to investigate the prevalence of overweight among male seafarers and to determine the maximum allowable body mass index among seafarers.

There are no statistical studies on this issue among Georgian seafarers. Therefore, it is relevant to conduct a study.

It is necessary to inform future seafarers and current seafarers about the problem so that they understand that being overweight is not just an aesthetic defect and that a seafarer is obliged to comply with international standards regarding weight.

Objective

The study aimed to determine the prevalence of overweight and obesity among Georgian seafarers.

Materials and Methodology

A retrospective study was conducted at the Batumi Seafarers' Medical Center "Sagittarius" based on data from 450 seafarers (men aged 20-60) who underwent medical examinations from 2016 to 2022. The study protocol included: medical examination, questionnaires, blood pressure monitoring, electrocardiogram, and anthropometry (measurement of body height and weight and calculation of body mass index). As well as biochemical blood parameters: the amount of high and low density lipoproteins, triglycerides, and glucose in the blood.

Body height and weight were measured using a standard medical stadiometer and scales, without clothing or shoes. The degree of overweight and obesity was determined using body mass index (BMI) according to the international classification (WHO, 1997) (Table N1).

The seafarers were divided into age groups: 20-29, 30-39, 40-49, and 50-60.

Results

Of the 450 seafarers examined, 9.5% had normal weight, 84.4% were overweight, and 6% were obese. The overall prevalence of overweight and obesity was 90.5% (Table N2).

The overall mean body mass index (BMI) among the examined seafarers was $26.9 \pm 0.5 \text{ kg/m}^2$. The average BMI data in all groups individually exceeded the existing norm and amounted to: 25.37 kg/m^2 in the 20-29 year old group, 26.92 kg/m^2 in the 30-39 year old group, 27.48 kg/m^2 in the 40-49 year old group, 27.84 kg/m^2 in the 49-50 year old group. There is an age-dependent increase in BMI indicators.

Table 1

Weight/Height squared	= kg/m^2
Body mass and obesity assessment	BMI (kg/m^2)
Body mass deficit	< 18,5
Normal weight	18,5-24,9
Overweight	25,0-29,9
Obesity (grade I)	30,0-34,9
Obesity (grade II)	35,0-39,9
Morbid obesity (grade III)	> 40

Source: Compiled by the authors, based on research results

Table 2. Body mass index data by age group

	Age group				Total
	20-29 years old	30-39 years old	40-49 years old	49-59 years old	
Underweight	-	-	-	-	-
Normal weight	26/31,7 %	13/9,55%	4/2,39%		43/9,5%
Overweight	54/65,8%	117/86,0 %	148/88,62 %	61/93,8%	380/84,4%
Obesity (Grade I)	2/2,43%	6/4,41%	15/8,98%	4/6,15%	27/6%
Obesity (Grade II)	-	-	-	-	-
Morbid obesity	-	-	-	-	-

Source: Compiled by the authors, based on research results

Table 3. Ratio of average body mass index data in different age groups

group p N	Age group	Absolute (%)	(kg/m ²)	p	
1	20-29 years old	82 (18,22%)	25,37±0,7	p1,2 = 0,1; p1,3 = 0,02; p1,4 = 0,006; p1,5 = 0,0001;	p2,4 = 0,14; p2,5 = 0,001; p3,4 = 0,41; p3,5 = 0,01;
2	30-39 years old	136 (30,22%)	26,92±0,5		
3	40-49 years old	167 (37,11%)	27,48±0,6		
4	50-60 years old	65 (14,44%)	27,84±0,6		
Total		450 (100%)	26,9±0,5		

Source: Compiled by the authors, based on research results

Conclusions

According to the study, the prevalence of overweight among Georgian seafarers is high (90.5%). Unfortunately, no statistical data from a similar population study were found in Georgia, and we cannot determine whether overweight is widespread only among seafarers or more generally in Georgia.

According to weight studies conducted among seafarers in Belgium, Italy, and Turkey, overweight and obesity amounted to 40%-60%, while this figure in the general population of the same countries is 35%-50%. It is noteworthy that the majority of Georgian seafarers (84.4%) were overweight, and obesity was found in 6%, while, for example, obesity was recorded in 12.5% of Turkish seafarers.

According to body mass index data, similar trends have been observed in other countries, with progressive growth with increasing age. BMI reaches its maximum - 27.84 - in the 50-60 year old age group. At the same time, the average BMI in all age groups exceeds the norm.

Our retrospective study included 450 sailors. According to the results, the weight of most Georgian sailors exceeds current international standards.

We continue the study in order to cover an expanded research base - a larger number of sailors. It is also necessary to conduct a study of the general population of Georgia and compare the results with those from a focus group of sailors. The maximum permissible BMI should be determined with consideration of the anatomical and constitutional features of Georgians.

Conclusion

We conclude that it is necessary to conduct educational and informational activities among both current and future sailors. The goal of such activities should be

to instruct seafarers on health requirements, healthy nutrition, physical activity rules, and the prevention and treatment of obesity.

REFERENCES

1. World Health Organization, WHO (03.2013). Fact Sheet – Obesity and Overweight.
<http://www.who.int/mediacentre/factsheets/fs311/en/index.html> (01.12.2013).
2. World Health Organization, WHO (2013). Health Topics, Obesity.
<http://www.who.int/topics/obesity/en/> (05.12.2013).
3. Nittari G, Tomassoni D, Di Canio M, Traini E, Pirillo I, Minciocchi A, Amenta F. Overweight among seafarers working on board merchant ships; BMC Public Health. 2019; 19: 45. Published online 2019 Jan. doi: 10.1186/s12889-018-6377-6;
4. Nas S, Fışkın R. A research on obesity among Turkish seafarers. Int Marit Health. 2014; 65:187–191. doi: 10.5603/IMH.2014.0036. [PubMed] [CrossRef] [Google Scholar]
5. Hansen HL, Hjarnoe L, Jepsen JR. Obesity remains a major health risk for Danish seafarers and fishermen. Int Marit Health. 2011; 62:98–103. [PubMed] [Google Scholar].
6. Bridger RS, Bennett AI. Age and BMI interact to determine work ability in seafarers. Occup Med (Lond) 2011; 61:157–162. doi: 10.1093/occmed/kqr003.
7. Roberts SE, Nielsen D, Kotlowski A, Jaremin B. Fatal accidents and injuries among merchant seafarers worldwide. Occup Med (Lond) 2014; 64: 259–266.
8. Andela CD, Van Haalen FM, Ragnarsson O, et al. Mechanisms in endocrinology: Cushing's syndrome causes irreversible effects on the human brain: a systematic review of structural and functional magnetic resonance imaging studies. Eur J Endocrinol. 2015; 173; R1–14.
<https://doi.org/10.1530/EJE-14-1101>
9. Pancic M, Ricka-Zauhar Z, Blazevic M. Analysis of risk factors and assessment of exposure to coronary diseases in seamen. 8th International Symposium on Maritime Health, Rijeka, Croatia. 2005.

THE IMPACT OF LOGISTICS ON BUSINESS PERFORMANCE

Nino Tchilaia

Associate Professor Batumi Navigation University

Ekaterine Chikovani

Associate Professor Batumi Navigation University

Abstract. This article explores the vital role that logistics plays in today's business environment. It discusses how logistics has become an essential part of a company's success and why it is a critical element in gaining a competitive advantage. In the global economy, logistics is crucial for companies to expand their markets and international operations. Efficient logistics allows for the quick and reliable delivery of goods worldwide. The authors emphasize that logistics encompasses a wide range of operations, from inventory management to route optimization. They examine the impact of logistics on delivery times, customer service levels, and storage costs. The authors also explore how modern technologies and logistics innovations enhance processes and increase efficiency. These advancements enable companies to significantly improve operational efficiency, strengthen competitiveness, and deliver higher levels of customer service. The article highlights the importance of logistics management for companies in the global market and how logistics supports global business integration. The authors cite successful companies that have achieved their goals by optimizing logistics processes. In conclusion, the article emphasizes that logistics is integral to modern business, and companies seeking efficiency and competitiveness must focus on it.

Keywords: Logistics as a factor of efficiency, supply management, inventory management, automation, and product delivery.

Introduction

In today's marketplace, competition is becoming increasingly fierce, requiring companies to adopt new and effective approaches to survive and thrive. Logistics, as a key factor, plays a vital role in achieving outstanding business results. This article examines the role and importance of logistics in today's business world and explores how it can become a defining element for achieving competitive advantage. In the context of accelerated technological change and dynamic shifts in consumer preferences, logistics has a significant impact on company success. From supply chain and inventory management to efficient and rapid product delivery to customers, every stage of the supply chain is crucial.

In this article, we will examine in detail how modern companies use logistics to improve their efficiency and competitiveness. We will discuss innovations in logistics,

such as automation, artificial intelligence, and digital platforms, their impact on business processes, and how to implement them. Logistics covers a wide range of operations, from supply chain and inventory management to efficient customer product delivery. Modern technologies and innovations have made logistics more complex and dynamic, offering companies numerous new opportunities to optimize processes and reduce costs. Automation of logistics operations allows companies to reduce manual labor, reduce the likelihood of errors, and speed up task execution. Examples include automated order management, warehouse robots for handling goods, and autonomous delivery vehicles. Artificial intelligence enables the analysis of large volumes of data to forecast demand, optimize routes, and manage inventory. Companies are also looking toward sustainable logistics solutions, such as electric and hybrid vehicles, route optimization to reduce CO2 emissions, and environmentally friendly packaging. Innovations in these areas improve efficiency, reduce costs, and enhance customer service. They can also help companies adapt to rapidly changing market conditions and customer demands. Implementing these innovations requires not only investment in technology but also changes in a company's culture and processes. However, they can be key to achieving competitive advantage and successfully surviving in the modern business environment. Overall, the role of logistics in modern business cannot be underestimated. It has become an integral part of successful enterprises and, more importantly, its influence continues to grow. Today, understanding, optimizing, and innovating logistics processes have become strategic priorities for companies seeking to remain competitive and efficient in today's dynamic economic environment. By analyzing the role of logistics and applying innovative approaches to improve it, we aim to demonstrate how it can become a key source of competitive advantage for organizations.

Results and Discussion

The literature review confirms that logistics has become an integral part of corporate success. It plays a critical role in achieving competitive advantage and enables companies to compete effectively in the global marketplace.

Logistics solutions enable companies to:

1. Reduce costs. Logistics can help companies reduce the costs of transportation, storage, production, and other processes.
2. Improve customer service. Effective logistics enables companies to deliver a higher level of service to customers, for example, by ensuring fast delivery and efficient order processing.
3. Increase profits. Logistics can contribute to a company's profit growth by reducing costs and improving customer service.

In an environment of globalization and increasing competition, logistics is becoming increasingly important for companies. In today's environment, companies must be able to move goods and information quickly and efficiently around the world to remain competitive. The literature review confirms this trend. Specific examples of how logistics helps companies achieve success can be found across various industries. In the automotive industry, logistics plays a vital role in ensuring the smooth production and delivery of vehicles to consumers. Logistics solutions enable companies to deliver parts and components worldwide quickly and efficiently. This allows companies to reduce production times and lower costs. For example, Toyota uses logistics solutions to ensure smooth vehicle production at its global factories. The company uses a just-in-time system, enabling it to receive parts and components exactly when needed. This helps the company reduce production times and lower costs.

In retail, logistics plays a vital role in ensuring the timely delivery of products to stores. Logistics solutions enable companies to reduce delivery times and improve customer service. For example, Amazon uses logistics solutions to ensure fast delivery of products to customers. The company uses a global network of warehouses and distribution centers, enabling it to deliver products to customers quickly and affordably.

In e-commerce, logistics plays a vital role in ensuring fast and affordable delivery of products to customers. Logistics solutions enable companies to reduce delivery times and improve customer satisfaction. For example, AliExpress uses logistics solutions to ensure fast delivery of goods to customers worldwide. The company partners with various logistics companies to offer customers a variety of delivery options.

These examples demonstrate that logistics plays a vital role in the success of companies across various industries. Logistics solutions enable companies to reduce costs, improve customer service, and increase profits.

Here are a few more examples of how logistics helps companies succeed:

UPS uses logistics solutions to ensure same-day package delivery in major US cities. This has allowed the company to increase its market share. Walmart uses logistics solutions to ensure two-day delivery of goods to stores. This has allowed the company to reduce storage costs and improve customer service. The Coca-Cola Company uses logistics solutions to ensure the smooth delivery of beverages to consumers. Coca-Cola uses logistics to deliver beverages from its factories to stores around the world. This allows the company to be present in markets across multiple countries. Nike uses logistics to ship goods from China to Nike stores around the world. This allows the company to offer its products to consumers in multiple countries. Apple uses logistics to deliver its products to China. This allows the company to enter one of the world's largest markets.

These examples demonstrate that logistics can be a powerful tool for company success and is an important factor in the globalization of business. Logistics is of global importance to companies (Table 1).

Table 1. Benefits of logistics for companies

Benefits of Logistics for Companies	Examples
Expanding Markets	A company can enter new markets by offering goods and services to consumers in other countries.
Carrying Out International Operations	A company can collaborate with partners in other countries, using logistics to deliver goods and services between these partners.
Reducing Costs	Efficient logistics can help a company reduce costs for transportation, storage, and other logistics processes.
Improving Customer Service	Efficient logistics can help a company improve customer service by enabling faster, more reliable delivery of goods.
Facilitating Global Business Integration	Efficient logistics facilitates global business integration, enabling companies from different countries to collaborate.

The data in Table 1 demonstrate that effective logistics enables companies to expand their markets, conduct international operations, reduce costs, improve customer service, and facilitate global business integration.

The diversity of logistics operations highlights their multifaceted nature and complexity. This aspect is important because logistics encompasses numerous stages and processes, beginning with inventory management, which includes not only storage but also planning, forecasting, and order management. Furthermore, logistics also addresses the selection of optimal transport routes, which involves solving complex problems of cargo distribution and routing.

The multifaceted nature and complexity of logistics operations highlight that effective logistics management requires a comprehensive, integrated approach. Companies striving for success must pay attention to every stage of the supply chain and continuously improve their processes to ensure reliable product delivery and customer satisfaction (Table 2).

Table 2. Stages of the logistics chain to ensure a reliable supply of goods and meet customer needs

Supply Chain Stage	Goal	Key Success Factors
Planning	Identify customer needs and develop a logistics plan that meets them.	Accurate understanding of customer needs, effective inventory management, selection of appropriate suppliers, and transport companies.
Purchasing	Purchase goods or services in accordance with the logistics plan.	Effective procurement management, identification of reliable suppliers, and conclusion of favorable contracts.
Storage	Store goods in a safe and convenient location.	Optimization of warehouse operations, ensuring product safety, and compliance with safety requirements.
Transportation	Transfer goods from the supplier to the customer.	Selecting the optimal route, ensuring product safety, and meeting delivery deadlines.
Distribution	Deliver goods to customers according to their needs.	Effective delivery management, ensuring customer satisfaction, and providing information on delivery status.
Returns processing	Customer returns.	Effective returns management, ensuring customer satisfaction, and minimizing return costs.

These stages of the supply chain are interconnected and must be coordinated to ensure reliable product delivery and customer satisfaction.

Logistics impacts delivery times, customer service levels, and storage costs. This demonstrates that effective logistics can significantly impact a company's business processes and financial results. Let's examine these aspects in more detail:

1. **Delivery times:** Prompt and accurate product delivery is essential for satisfying customer needs and maintaining their loyalty. Effective logistics can reduce delivery times, which is especially important in today's fast-paced business environment.
2. **Customer service levels:** Logistics directly impacts customer service levels. Fast and accurate delivery, along with proper inventory management, ensures customers receive the products they need on time, helping to meet their needs and strengthen long-term relationships.
3. **Storage costs:** Optimizing logistics processes can reduce storage costs. This includes reducing the need for warehouse space and optimizing inventory. Research into these aspects shows that logistics is not merely an operational activity but also a strategic element that contributes to competitive advantage and improved financial performance. Company leaders must pay attention to this aspect and invest

in its optimization.

Modern technologies and innovations in logistics significantly improve the efficiency of logistics processes. These technologies and innovations enable companies to:

1. Optimize logistics operations. For example, the use of artificial intelligence (AI) and machine learning (ML) can help companies optimize delivery routes, forecast demand, and manage inventory. AI and ML can be used to analyze
2. Large volumes of data to determine the most efficient delivery routes. They can also be used to analyze sales data, market trends, and other factors to predict future demand for goods or services. Furthermore, AI and ML can be used to analyze sales data, expiration dates, and other factors to determine optimal inventory levels. This can help companies avoid over- or under-stocking. Amazon uses artificial intelligence and machine learning technologies to optimize delivery routes. This allows the company to reduce fuel costs and improve delivery times. As a result, Amazon can offer its customers faster and more reliable delivery, which is one of its key competitive advantages.
3. Automate logistics processes. For example, robots and drones can help companies automate warehouse operations and product delivery. Robots can be used to perform repetitive tasks in warehouses, such as order picking, palletizing, and transporting goods. This can help companies increase productivity and reduce costs. Drones, in turn, can be used for short-distance deliveries, such as food or package delivery. This can help companies reduce delivery times and improve customer service. Walmart uses robots to automate warehouse operations. This allows the company to process more orders and deliver goods to customers faster. As a result, Walmart can reduce storage costs and improve the efficiency of logistics operations.
4. Improve product traceability. For example, the use of RFID and GPS technologies allows companies to track the location of goods in real time. RFID technology allows companies to track the location of goods in warehouses and during delivery. This can help companies provide customers with delivery status information. GPS technology allows companies to track the location of vehicles transporting goods. This can help companies manage inventory and prevent loss. DHL uses RFID technology to track the locations of goods in real time. This allows the company to provide customers with delivery status information. As a result, DHL can improve customer service and increase customer satisfaction.

Benchmarking the logistics practices of different companies reveals best practices that can be adapted to improve efficiency (Table 3). These practices include the use of artificial intelligence and machine learning technologies, automation of logistics operations, and real-time product tracking. Implementing these improvements can help companies reduce costs, improve customer service, and increase competitiveness.

Based on an analysis of logistics practices at various companies, the following improvements can be implemented based on logistics best practices:

1. Expanding the use of AI and machine learning technologies to optimize other

logistics processes, such as demand forecasting and inventory management. This can help companies reduce costs and improve customer service.

2. Expanding the use of robots to automate other logistics operations, such as transportation and cargo handling. This can help companies improve productivity and reduce costs.
3. Using RFID technologies to track other logistics metrics, such as vehicle location and inventory status. This can help companies improve customer service and reduce waste.

Table 3. Comparative analysis of logistics practices of different companies

Company	Logistics practice	Comments	Possible improvements
Amazon	Using artificial intelligence and machine learning technologies to optimize delivery routes	An effective way to reduce fuel costs and improve delivery times	Using AI and machine learning technologies to optimize other logistics processes, such as demand forecasting and inventory management
Walmart	Using robots to automate warehouse operations	An effective way to increase productivity and reduce costs	Expanding the use of robots to automate other logistics operations, such as transportation and cargo handling
DHL	Using RFID technology to track the location of goods in real time	An effective way to improve customer service and reduce losses	Using RFID technologies to track other logistics metrics, such as vehicle location and inventory status

The above demonstrates that logistics plays a vital role in modern business and that innovative approaches to improving logistics can significantly increase organizations' competitiveness. Here are several ways logistics can become a key source of competitive advantage:

1. Improving operational efficiency. The use of new technologies, such as warehouse management systems (WMS), transportation management systems (TMS), artificial intelligence, and machine learning, optimizes route planning, inventory management, and order processing, reducing costs and delivery times. Innovative solutions, including blockchain and the Internet of Things (IoT), improve transparency in logistics operations. This helps manage risks, improve cargo tracking accuracy, and ensure secure deliveries. The use of sustainable logistics practices and technologies reduces the negative environmental impact, which can be a significant competitive advantage in light of growing consumer environmental awareness.
2. Inventory optimization, improved customer service. Using analytics and big data to forecast demand and optimize inventory levels reduces storage costs and minimizes

losses from excess inventory. Innovations in logistics can help improve customer service by providing more accurate delivery times, order status tracking, and more flexible delivery options.

3. Global market expansion and competitive conditions. Innovations in logistics can help organizations expand globally by ensuring efficient delivery of goods across countries and regions. Optimized logistics processes can reduce shipping costs and offer more competitive rates, attracting new customers and increasing loyalty among existing ones.

Thus, logistics, enhanced by innovation, can be a key factor in achieving significant competitive advantage for organizations, enabling more efficient operations, improved customer service, and reduced costs. The use of modern technologies such as artificial intelligence (AI) and machine learning (ML) enables the automation of many logistics operations. This includes delivery routing, inventory management, demand forecasting, and route optimization, reducing the time and resources spent on these tasks. Collecting and analyzing data on logistics operations allows organizations to make more informed decisions. Analytics enables inventory optimization, improved demand forecasting, and the identification of potential bottlenecks in the process. Electric and autonomous vehicles, as well as drones and delivery robots, reduce costs and improve delivery accuracy and speed. The transition to more environmentally friendly technologies and transportation methods helps reduce environmental impacts and meet the needs of eco-conscious customers. Using specialized software solutions and algorithms to find optimal routes saves fuel, reduces time, and reduces emissions. Smart devices and sensors can provide real-time status information on cargo and equipment, improving logistics management.

Overall, innovations in logistics enable organizations to create a more flexible, adaptive system that serves customers more effectively, reduces costs, and achieves a competitive advantage in the marketplace. Investing in logistics innovation is becoming a strategically important step for organizations in modern business.

Conclusion. Based on the analysis of the role of logistics as a key factor in business performance, the following conclusions can be drawn:

1. The study confirms that logistics is a key element of a company's success. Effective management of logistics processes enables businesses to achieve high efficiency and meet customer needs. Logistics plays a critical role in achieving competitive advantages and enabling companies to compete effectively in the global market. One key finding is the link between logistics quality and customer satisfaction. Businesses should actively work to optimize delivery and service to build long-term customer relationships.

2. It has been proven that effective logistics reduces costs and optimizes resource utilization, which contributes to increased profits and competitiveness. The study also emphasizes the importance of incorporating logistics into strategic business planning. It should be viewed as a strategic tool for achieving company goals. Businesses must be prepared to adapt their logistics systems in response to changing market conditions and customer demands. Flexibility in logistics is becoming a key competitive advantage. Supply chains play a vital role in logistics, and their effective management helps optimize procurement and distribution processes.
3. Technology is proven to be transforming logistics. Modern technologies and management systems have become catalysts for changing logistics operations, increasing their efficiency and reducing costs. These changes, along with the benefits of implementing modern technologies in logistics, have a profound impact on various aspects of business and society. Thanks to modern technologies, companies can provide a higher level of service, which contributes to customer satisfaction and the formation of long-term relationships. Technologies help reduce delivery times, which is especially important amid growing interest in online shopping and expectations for fast delivery. Modern management and monitoring systems provide greater access to global markets, enabling companies to expand their operations beyond national borders. Technology can help reduce resource consumption, such as fuel and materials, which is important for both businesses and the environment. Technology enables more effective security monitoring and risk management in logistics operations, particularly for the transportation of valuable and hazardous goods. The integration of technology into logistics supports companies' overall digital transformation, enabling them to remain competitive in today's digital economy.
4. Thus, modern technologies are truly transforming logistics and have a profound impact on business, society, and the economy as a whole. Companies that actively implement and use these technologies can expect significant competitive advantages and contribute to more efficient, sustainable logistics and overall business development.
5. It has been proven that logistics management not only helps optimize internal processes but also contributes to increased profitability, customer satisfaction, and overall company competitiveness. Firstly, companies that can deliver goods or services quickly and reliably typically have an advantage over competitors. This can lead to increased market share and a stronger market position. Customers increasingly value service quality, including delivery speed and order fulfillment accuracy. Secondly, improving logistics processes helps increase customer satisfaction, which in turn fosters loyalty and repeat purchases. Optimizing logistics can reduce a company's costs for storage, transportation, and inventory management.

This increases profitability and competitiveness. Well-established logistics processes help build long-term customer relationships. Thirdly, in the context of the global economy and global trade, logistics enables companies to compete effectively in the global market. Effective logistics facilitates the export and import of goods, expanding the company's geographic reach.

6. The study emphasizes the need to invest in modern technologies and management systems to improve logistics operations and increase efficiency. Modern technologies and management systems have become integral to logistics operations. They not only improve the efficiency and reliability of processes but also provide companies with valuable information for more informed decision-making. Investments in modern logistics technologies can make a company more competitive in the market. The ability to deliver quickly, accurately, and reliably can provide a significant advantage over competitors. Management and monitoring systems enable closer customer interaction, providing them with information on order status and product tracking. This contributes to increased customer satisfaction. Optimizing logistics processes with technology can save companies money by reducing warehousing, transportation, and inventory management costs. Modern systems provide rich analytical information that can be used to optimize logistics strategies, forecast demand, and develop more effective business plans.

Overall, the study confirms that investing in modern technologies and management systems for logistics operations is not only justified but also a strategic necessity for companies striving for success and growth in the modern business environment. These investments increase efficiency, competitiveness, and customer satisfaction, ultimately supporting sustainable development and high performance. Logistics is a key factor in business success and should be treated as a strategic asset that requires attention and investment. Its role in modern business cannot be overstated, and optimizing logistics processes can lead to significant improvements in a company's results.

References:

1. Baker M.J. Dictionary of Marketing and Advertising, 2nd ed. New York: Nickhols Publishing, 2019.
2. Ballou R.H. Business Logistics Management. 3rd ed. Prentis Hall International, Inc., 2023.
3. Bernard I. Demand Management France. Leuven: Interbrew, Logistics Department, 2020, 15 p.
4. Bowersox D. J., Closs D. J. Logistical Management. The Integrated Supply Chain process. The McGRAW- HILL Companies, Inc., New York, 2016.;

5. Coyle J.J., Bardi E.J., Langley C.J.J. The Management of Business Logistics, 5th ed. St.Paul, MN: West Publishing Co., 2024
6. Ericsson D. Business Resource Management: a Framework for Strategic Management of Materials Flow//The Gower Handbook of Logistics and Distribution Management, 1990.;
7. Fogarty D. W., Hoffman T. R. Production and Inventory Management. -South Western Publishing, 1983.;
8. Goes J. Customer Service. Logistics Belgium. Leuven: Interbrew, Logistics Department, 2000, 45 p.
9. Hansen T., Voller C, Stensballe B. Design for Logistics: Methodology Proposal and Case Study/Proceedings of the International Conference on Industrial Engineering and Production Management. Morocco, Marrakech, FUCAM, EST, EMI, 1992.
10. Hutchinson N.E. An Integrated Approach in Logistics Management. - Englewood Cliffs, NJ: Prentis Hall, 1987.
11. Langley C. J. The Evolution of the Logistics Concept//Journal of Business Logistics, №2, 1979, v. 7.;
12. Logistics Key Performance Indicators 2000. Leuven: Interbrew, Logistics Department, 2000, 45 p.
13. Magee J.E., Capacino W.F., Rosenfield D.B. Modern Logistics Management: Integrated Marketing and Physical Distribution. New York: John Wiley, 2015.
14. Moller C, Johansen J. Logistical Efficiency: A Conceptual Framework. Proceedings of the 8th IPS research seminar / Aalborg University, 2023;
15. Moller C, Johansen J. Paradigms in Logistics. Department of Production, University of Aalborg, Denmark, 2023,
16. Porter M. E. Competitive Advantage. The Free Press, New York, 1985.
17. Robenson J.F., House R.G.//The Distribution Handbook. - New York, 2025
18. Stevenson W. J. Production / Operation Management. — Irwin-Homewood-IL, Boston, MA, 2023
19. Stock J. R., Lambert D. M. Strategic Logistics Management, 2nd ed. — Homewood Cliffs, IL: Richard D. Irwin, 2017.
20. Supply Chain Management Development Concept: 2022-2025.
21. Tersine R.J., Materials Management and Inventory System. Elsevier North-Holland Publishing, 3rd ed., 2017.
22. Total Quality Management. London, British Standards Institution, 2022.
23. Total Quality Management. Teaching Material. TACIS'D 062. Milan, 2024.
24. Welcome to Jupille. Logistics Presentation. — Jupille: Interbrew, Logistics Department, 2023

COMPARATIVE ANALYSIS OF HEALTHCARE MANAGEMENT SYSTEMS: EXPERIENCE OF GEORGIA AND NEIGHBOURING COUNTRIES

Elida Khvedelidze

Doctor of Medicine, Associate Professor of BNU

Ekaterine Gvarishvili

Doctor of Medicine, Associate of BNU

Abstract. The study aims to evaluate changes in the management style and qualifications of medical managers in Georgia that arose from the introduction of foreign specialists' experience and the return of students educated abroad. To achieve this, the study compares healthcare systems in Georgia, the United Kingdom, and various European Union countries, specifically Greece, Portugal, Germany, Sweden, the Netherlands, Spain, and Italy, while surveying medical managers. The research examines various aspects of the healthcare management system in these regions. Centralized and decentralized management models are compared, their advantages and limitations identified, and the degree of autonomy of medical managers is analyzed based on the specifics of healthcare financing in each country. The findings reveal that decentralization of management contributes to greater flexibility in decision-making, although it may result in an uneven distribution of resources. In contrast, centralized systems ensure uniform service quality but often restrict local managerial autonomy. Survey data from Georgian medical managers indicate that 70.7% of respondents positively evaluated the impact of international management practices on the operations of medical institutions, particularly in strategic planning and resource optimization. However, adapting new methods is challenging: 22.1% of participants report seeing no substantial changes, and 7.2% cite barriers related to administrative regulations and insufficient staff training. Furthermore, more than half of the respondents highlighted improved staff coordination and increased transparency in resource management. Nonetheless, challenges persist in securing financial support for reforms and in providing systematic training for specialists. The results underscore the necessity of a comprehensive approach to healthcare reform, which should include changes to the funding structure, a review of management models, enhancements to staff skills, and stronger coordination between the public and private sectors.

Keywords: Centralization and decentralization; economic efficiency; digitalization; autonomy; professional competencies.

1. Introduction

The sustainability and effectiveness of healthcare are influenced by many factors, including financing, management decisions, personnel policies, innovation, and the system's ability to adapt to change. For many countries, finding a solution that will ensure the availability of medical care while maintaining their financial stability remains an important task. How efficiently resources are allocated, how well-balanced management decisions turn out to be, and how stable the system itself is—all these factors depend on medical management.

The review of transformational processes in medical systems is particularly fascinating in this context, especially in Georgia, where healthcare reforms are accompanied by economic and institutional changes stemming from the transition from a centralized management model to a market economy. External factors, such as international experience, macroeconomic shifts, and reforms in the system of state regulation, can influence the management structure of medical institutions and shape new approaches to organizing specialists' work, personnel policy, and strategic development. In such conditions, the adaptability of the healthcare system and the effectiveness of management mechanisms become especially important.

Financing, insurance, and personnel policy have become central issues in shaping Georgia's new healthcare system. A. Jorbenadze and T. Verulava (2022) evaluated the initial stage of transformation and highlighted the difficulties of the transition from the Soviet model to market mechanisms and the consequences of economic instability that complicate the implementation of reforms. Further, T. Verulava (2023) analyzed the transformation of the health insurance system and concluded that the gradual introduction of universal insurance programs reduced the financial burden on patients but did not address the long-term sustainability of financing. The human resources issue was examined by D. Tabidze et al. (2022), who identified an acute shortage of qualified specialists and a lack of effective mechanisms for personnel administration. Difficulties in balancing public and private financing and staff shortages have created a need to identify management models that ensure the sustainability of the healthcare system and enable more efficient resource allocation.

Research on the financial sustainability of healthcare has revealed the difficulty of finding a balance between government and market financing. W.O. Cleverley (2024) analyzed the impact of various financing models on the economic efficiency of medical organizations. The author identified the need for strategic cost management, pricing control, and the adoption of digital solutions to optimize costs and noted that excessive increases in healthcare costs, without proper regulation, can reduce the availability of medical care and destabilize the system financially. R. Kosklin et al. (2022) analyzed knowledge management in healthcare and pointed out the fragmentation of existing

approaches, which hinders effective resource allocation and innovation. The authors concluded that using digital platforms and data analytics can improve the efficiency of medical institutions, but these technologies require substantial investments and a review of management mechanisms. Despite the potential of combined financing and knowledge management models, the issue of effective strategies for long-term financial sustainability of healthcare without reducing the quality of medical services remains unexplored.

The issue of effective leadership and change management in healthcare remains controversial in the scientific community. The disadvantages of the traditional hierarchical model, which limit coordination between management levels and reduce the system's adaptability, were identified by K. Willocks and S. Moralee (2021). Similar conclusions were drawn by J. Barr and L. Dowding (2022). As the lack of managerial skills among healthcare professionals hinders the implementation of strategic solutions and impedes reform, the transition to collective leadership and interdisciplinary collaboration can enhance the sustainability of the healthcare system. R. Harrison et al. (2021) examined the complexity of implementing changes and identified staff resistance and structural barriers as the main factors slowing down reforms; effective change requires integrating strategic management, employee engagement, and continuous evaluation of results.

The restructuring of management models in healthcare amid crises and digital transformation is increasingly relevant. Remote guidance as a tool for adapting medical institutions to unstable conditions was assessed by A. Terkamo-Moisio et al. (2021). The authors concluded that digital technologies allow for flexible management but require a review of staff coordination strategies. Therewith, J.M. Geerts et al. (2021) analyzed crisis management in healthcare after the COVID-19 pandemic in terms of a balance between operational solutions and long-term system development. The study results showed that investments in digitalization and telemedicine are not only necessary but also essential to the sustainability of future medical organizations. Thus, further study is required to determine how medical institutions can integrate these changes without substantial losses to their internal structure.

Despite the extensive investigation of financing, insurance, personnel policy, and management strategies in healthcare, the impact of external factors on the transformation of medical management, including the role of international experience, economic changes, and government regulatory reforms, remains insufficiently disclosed. In this regard, the present study aimed to evaluate how external factors influenced approaches to medical management, the level of managers' professional qualifications, and organizational changes in Georgian medical institutions. The following tasks were set to achieve this goal: determine the influence of international

experience on management decisions, analyze the relationship between economic factors and personnel changes in the healthcare system, and identify barriers to effective reform of medical institutions in Georgia.

2. Materials and methods

This study conducted a comparative analysis of healthcare management systems in the European Union (EU) countries (Greece, Portugal, Germany, Sweden, the Netherlands, Spain, and Italy), Great Britain, and Georgia. To examine management models in the EU, countries with different approaches to healthcare organization, including centralized and decentralized systems, were selected. The analysis covered parameters such as the degree of autonomy of medical managers, funding sources, control mechanisms, and the digitalization of resource management. As sources of information, official documents (Presidency..., 2024; The King's Fund, 2024; Federal Ministry..., 2024b; Swedish Parliament, 2017; Civil Protection Department, 2025; Federal Ministry..., 2024a), legislative acts (Netherlands Tax Authorities, 2024; Official State..., 1986; European Union, 2011; European Union, 2005), and reports of international organisations (European Medicines Agency, 2025; European Database on (Medical Devices, 2017; European Union, 2024; European Union, 2025a; European Union, 2025b) were used, which allowed assessing the specific features of medical management in selected EU countries.

The analysis of the healthcare management system in Georgia included a review of the legislative framework governing medical institutions (Legislative Herald of Georgia, 2004), government funding programs (Transparency International Georgia, 2013), and organizational structures (State Procurement Agency, 2025). The autonomy of medical managers in public and private institutions, the mechanisms of interaction between the state and the private sector, and the dynamics of reforms aimed at improving management efficiency were also considered, and a comparison of management parameters in healthcare in the EU and Georgia was implemented.

2.1. Sample description

The survey aimed to assess the impact of international management practices on the Georgian healthcare system. The study involved 307 medical managers (61.9% men and 38.1% women) with an average age of 46.9 years. The sample was not randomly formed. The selection criteria included more than 5 years of managerial experience in the Georgian healthcare system. The selected respondents held positions as chief physicians, department heads, clinic administrators, medical service quality managers, and financial directors at medical organizations. Most participants (68.1%) had more than 10 years of experience in medical management.

To meet ethical standards, the study adhered to the principles of voluntariness, confidentiality, and anonymity. All participants were informed about the study's objectives, and their consent was obtained before completing the questionnaire. The names of medical institutions were not disclosed to comply with professional ethics and protect information.

2.2. The experiment process

The survey of respondents was conducted online using a questionnaire through the Google Forms platform. The participants were emailed instructions and a link to a questionnaire containing the following questions (Table 1).

Table 1. Experiment questionnaire

Question	Answer options
<i>Block 1: Closed questions</i>	
1. How do you assess the changes in management approaches in your institution after the introduction of the experience of foreign managers?	a. Substantial changes b. Minor changes c. No changes d. I find it difficult to answer
2. How often has your institution started using methods and approaches typical of foreign medical organizations?	a. Very often b. Sometimes c. Rarely d. doNever
3. How do you assess the impact of the return of foreign education specialists on your institution's management style?	a. Very positive b. Positive c. Neutral d. Negative e. Very negative
4. Has your institution's approach to planning and allocating resources (financial, human, and material) changed after the introduction of international practices?	a. Yes, substantially b. Yes, slightly c. No, it has not changed. d. I find it difficult to answer
5. How do you assess the impact of international practices on the economic efficiency of your institution (cost reduction, improved service quality, increased revenue)?	a. Very positive b. Positive c. Neutral d. Negative e. Very negative
6. Which management aspects have been improved in your institution due to foreign experience? (Select whatever is applicable)	a. Improving the quality of service b. Cost optimization c. Improving staff performance d. Improving financial performance e. Increased transparency and accountability f. Other
7. How do you assess the change in the qualifications of managers in your institution after introducing new	a. Substantially increased b. Slightly increased c. No changes

management methods borrowed from international experience?	d. Decreased e. Substantially decreased
<i>Block 2: Open questions</i>	
1. How have the changes related to introducing foreign methods affected your institution's internal work organization (for example, communication, problem-solving, personnel management)?	
2. Which international practices or approaches have proven to be the most useful for your institution, and which are challenging to implement?	
3. How did the returning specialists with foreign education influence your institution's development? Please share some examples.	
4. If you could improve the process of introducing international experience into your medical center, what would you suggest?	

Source: compiled by authors.

The answers to the first block of questions were processed and analyzed in Excel using formulas to calculate the percentage distribution. The answers to the second block of questions were analyzed using content analysis.

3. Results

3.1. Approaches to the management of medical institutions and the economic component of medical management in the EU countries

Effective management of medical institutions largely depends on their organizational structure and the degree of decision-making freedom managers have. These factors determine how flexibly and quickly medical organizations can adapt to changes, innovate, and improve the quality of patient care.

The management structure determines who makes key decisions in the healthcare system: government agencies, regional administrations, private companies, or the medical institutions themselves. It affects the speed of decision-making, the allocation of financial resources, and the ability to modernize infrastructure.

Medical managers' autonomy reflects the extent of their authority in managing their institutions' personnel, finances, and strategic development. High autonomy allows management to adapt to specific conditions, reduce costs, and increase efficiency. However, insufficient control can lead to inconsistencies with government priorities and health standards. The balance between centralized control and managerial autonomy is a key factor affecting the sustainability of the healthcare system, its financial efficiency, and the quality of medical services.

Healthcare management systems in the European Union can be roughly divided into centralized and decentralized (Greer, 2021; Greer et al., 2022; Jiménez-Rubio, 2022). This factor determines who makes key decisions about financing, the organization of medical care, and the regulation of institutions.

In centralized healthcare systems, management is conducted at the state level, ensuring control over service quality and equal access to medical care. In Greece, for example, the Ministry of Health controls the state-owned ESY hospital network (Εθνικό Σύστημα Υγείας, National Health System), which is funded by taxes (Tountas et al., 2020). A similar model operates in Portugal, where the National Health Service (SNS, Serviço Nacional de Saúde) coordinates the activities of regional offices (Presidency..., 2024). In the UK, the NHS (National Health Service) operates on a budget allocated by the Department of Health and the National Insurance (The King's Fund, 2024), enabling centralized management of resources and planning of medical infrastructure.

Decentralized healthcare systems transfer management authority to the regions or the private sector, providing more flexibility and promoting competition. In Germany, the key role is played by compulsory health insurance companies (Krankenkassen), whose work is regulated by the Social Code SGB V (Sozialgesetzbuch Fünftes Buch, Social Code Book V) (Federal Ministry..., 2024b). The Federal Ministry of Health determines the general policy, but the direct administration remains with the insurance funds. In Sweden, 21 regions (län) are responsible for organizing healthcare, funded by local taxes under the Law on Healthcare and Medical Services (Hälso- och sjukvårdslagen, HSL) (Swedish Parliament, 2017). In the Netherlands, healthcare management is based on competition among private insurers, whose activities are regulated by the Law on Health Insurance (Zorgverzekeringswet, Zvw) (Netherlands Tax Authorities, 2024).

The difference between centralized and decentralized systems determines the degree of government influence on medical institutions' work. The centralized approach guarantees uniform service quality but limits management's flexibility. Decentralisation, in turn, creates opportunities for innovation and adaptation to local conditions, but it can lead to an uneven distribution of resources. The choice of the system depends on the country's economic, political, and social characteristics.

The level of autonomy of medical managers in Europe largely depends on the model of healthcare financing, government regulation, and historically established traditions of medical institution management. In countries with centralised management, healthcare is subject to strict government control, whereas in insurance models, managers receive more freedom in decision-making.

In Spain and Italy, centralised healthcare management is based on the state's decisive role in financing and administering institutions. In Spain, the medical system is regulated by the Universal Health Care Act of 1986 (Ley General de Sanidad, 14/1986) (Official State..., 1986), which consolidated centralised financing and state control over resources. The Italian system is also based on strict regulations defined by

the National Health Service (Servizio Sanitario Nazionale, SSN) (Civil Protection Department, 2025), in which key decisions are made at the regional level within the framework of state standards. Centralised management limits managers' autonomy, forcing them to follow government budget priorities, regulations, and staffing constraints.

The historical development of insurance medicine and competition among healthcare providers drives the decentralized approach in Germany and the Netherlands. The German healthcare system was established by the Medical Insurance Act of 1883, adopted under Bismarck (Federal Ministry, 2024a), which laid the foundation for insurance financing. The Netherlands has had a Health Insurance Law (Zorgverzekeringswet, Zvw) since 2006 (Netherlands Tax Authorities, 2024), which obliges citizens to purchase private health insurance, and clinics operate as independent business units competing for funding. Thus, conditions were created under which managers have more authority in financial management, personnel policy, and strategic development of institutions.

Healthcare economics is also an important factor in the management of medical institutions, as it determines their sustainability, service accessibility, and quality of care (Bertram et al., 2021; Owusu et al., 2021; Folland et al., 2024). Financial decisions at the management level affect resource allocation, staff effectiveness, and a medical organization's long-term development strategy.

The main task of economic management in medicine is balancing costs and service quality. Limited budgets require optimal use of financial resources, including effective cost planning, control over the purchase of medical equipment and medicines, and the introduction of digital solutions to increase transparency in financial flows.

The sustainability of health facilities also depends on financing sources, whether government subsidies, insurance payments, or private investment. The variety of financing models and their combinations directly affect the availability of medical services to the public and the financial independence of institutions.

Table 2. Advantages and disadvantages of healthcare financing models

The financing model	Description	Advantages	Disadvantages
Beveridgian (state-owned)	Funded by taxes, medical services are free or almost free. The state manages medical institutions.	Universal access to medicine, low patient costs	High tax burden, queues, and lack of funding are possible
Bismarckian (insurance)	It is based on mandatory insurance premiums. Medical institutions often	High levels of medical care and competition among	High cost of insurance premiums, uneven access to

	operate as private organizations but are subject to government regulation.	insurers improve service quality.	medicine for different segments of the population
Mixed	A combination of government financing and insurance mechanisms. Varying degrees of private involvement in healthcare management	Flexibility in financial management, the ability to choose a treatment system	Uneven quality of services, difficulties in administration, and financing.

Source: compiled by the authors.

Proper management of economic processes in healthcare increases operational efficiency and ensures system stability, thereby reducing the burden on doctors and patients. In this context, medical management plays a critical role in guiding financing and resource allocation, enabling medical institutions to adapt to changes, increase efficiency, and ensure the long-term sustainability of the healthcare system. Table 2 shows the existing financing models and their advantages and disadvantages.

The medical industry uses digital technologies to enhance treatment quality, streamline administrative processes, and enhance resource management. Implementing such solutions helps medical institutions plan their work more efficiently, reduce costs, and ensure wider access to services.

One practical result of digitalization is the automation of processes: electronic medical records, hospital workflow management systems, and remote patient monitoring greatly simplify the medical staff's work. In addition, digital technologies help optimize financial and material resources, which is especially important in limited budgets and growing demand for medical services. Effective resource management involves sound financial allocation, personnel planning, drug inventory management, and patient needs analysis. Analytics and artificial intelligence tools enable the prediction of healthcare system burden and help prevent shortages of equipment, doctors, or medicines.

Despite the differences in the healthcare systems of individual states, the EU is implementing mechanisms that promote coordination and efficiency in this area: Directive 2011/24/EU (European Union, 2011) allows patients to receive medical care in any EU country with subsequent cost compensation, Directive 2005/36/EC (European Union, 2005) simplifies the recognition of doctors' diplomas, EMA (European Medicines Agency, 2025), and EUDAMED (European Database on Medical Devices, 2017) monitor the safety of medicines and medical equipment.

In addition, there are initiatives to introduce electronic medical cards and remote treatment (eHealth) (European Union, 2025a), data exchange (European Health Data

Space, EHDS) (European Union, 2024), and collective procurement of medicines and equipment (Joint Procurement Agreement, JPA) (European Union, 2025b).

The EU's uniform regulations improve the quality of medical services, increase coordination among countries, and ensure a more equitable distribution of medical resources, thereby forming a sustainable and efficient healthcare system in Europe.

3.2. Management of medical institutions in Georgia

Georgia's healthcare system is managed under a mixed model that combines government regulation and private initiative. Healthcare is administered by the Ministry of Labor, Health, and Social Protection of Georgia (Legislative Herald of Georgia, 2004), which develops state policy, regulates the activities of medical institutions, and monitors the quality of medical services. The funding is provided by the State Universal Healthcare program (Transparency International Georgia, 2013), which was launched in 2013. It guarantees the population's access to medical services through government funding, while funds are managed in cooperation with private medical institutions.

The level of autonomy of medical managers varies by institution type: public hospitals and clinics are under the strict control of the Ministry of Health, which determines their budgets, personnel policies, and standards of care. On the other hand, private medical centers have greater freedom to manage resources, make personnel decisions, and develop internal procedures. However, they are also subject to mandatory standards set by regulatory authorities.

Thus, Georgia's healthcare management structure combines state control over key aspects of the system with elements of a market economy, striking a balance between access to medical care and competition among service providers. However, the degree of autonomy for medical managers remains limited in public institutions, whereas the private sector offers more opportunities for independent decision-making.

The degree of managerial autonomy of medical managers in the EU and Georgia differs at the legislative level and in the actual decision-making practice. It is known that the degree of freedom of medical institutions varies in the EU: in insurance models (Germany, the Netherlands), managers have broad control over budgets and personnel policies, while in centralized systems (Spain, Italy) their powers are limited by government regulation (Vampa, 2021; Capano&Lippi, 2021; Bach, 2022). However, even in highly autonomous countries, government control mechanisms persist through insurance funds, regulations, and quality-monitoring tools.

Table 3. Comparison of management parameters in healthcare in the EU and Georgia

Parameter	EU	Georgia
Financial autonomy	In countries with an insurance model (Germany, the Netherlands), medical institutions are financially independent, receive funds from insurance funds, and allocate their budgets independently. In centralized systems (Spain, Italy), funding comes from the state budget, and important decisions are made at the state level.	In private clinics, financing occurs through market mechanisms, which gives greater flexibility. In government institutions, the Ministry of Health tightly controls the budget, limiting the scope for autonomous financial planning.
Personnel policy	In countries with decentralized systems, personnel decisions, including hiring, remuneration, and personnel strategy, are made at the institutional level. In centralized systems (Spain, Italy), the state regulates personnel issues such as salaries and job standards, but operational management remains with the institutions.	Personnel policy is entirely autonomous in private clinics. In government institutions, the most significant personnel issues (for example, the appointment of management, the allocation of rates, and the salary fund) are overseen by the Ministry of Health. However, day-to-day personnel decisions are made at the institutional level.
Management and control	In EU countries with high autonomy, the state only sets the framework but does not interfere in operational management (Germany, the Netherlands). In centralized systems (Spain, Italy), government control extends to financing, strategic development, and personnel policy.	Government institutions have a high level of government control: funding, personnel policy, and important decisions are determined by the Ministry. Regulations and licensing govern private clinics but leave managerial autonomy intact.
Flexibility in strategic development	Medical institutions in countries with an insurance model are highly flexible and independently develop strategic plans. In centralized systems, innovations are introduced through government programs.	Flexibility is present in private clinics, but in public institutions, strategic decisions are made at the Ministry level, which limits the speed of implementing reforms and new management approaches.

Source: compiled by authors based on Official State... (1986), Federal Ministry... (2024a; 2024b), Netherlands Tax Authorities (2024), Civil Protection Department (2025).

In Georgia, the situation is formally similar: private medical institutions have considerable autonomy in management, but licensing, regulatory authorities, and bureaucratic barriers limit their absolute autonomy. In public hospitals, managers have virtually no influence over financing and strategic development, leaving the system

dependent on centralized solutions. However, unlike in EU countries, where regulation is based on clear principles and control mechanisms, the system in Georgia is more susceptible to administrative influence and less predictable. European Directives ensure transparency and uniform standards across all countries. In contrast, in Georgia, similar mechanisms are absent or operate in fragmented ways, complicating long-term planning and increasing the dependence of management decisions on the political situation. Other parameters are shown in Table 3.

Thus, despite the differences in formal regulation, public medical institutions in both the EU and Georgia face limited autonomy in practice. The main difference lies in the degree of predictability and transparency of the system: in EU countries, even centralized regulation provides managers with clear frameworks and mechanisms for their work, whereas in Georgia, the limiting factors are less systemic, making the management of medical institutions less predictable and more dependent on administrative decisions.

The economic component of medical management in Georgia has been shaped by government initiatives, private investment, and international support, resulting in a heterogeneous funding structure. In an attempt to increase the efficiency of resource allocation and accessibility of medical care, reforms have been implemented (for example, the introduction of a State Universal Health Programme (2013), the optimisation of the procurement system through electronic tenders (State Procurement Agency, 2025) and a partially decentralised approach to the management of public health facilities (Chanturidze et al., 2009), but their results they remain contradictory. The State Universal Health Care Programme (2013) is the central instrument of state support, but its scale and sustainability depend on budgetary capacity. A substantial share of the costs is covered by private payments, which increases the burden on households and exacerbates unequal access to health services.

One of the key challenges remains the search for sustainable cost optimisation mechanisms. The introduction of the DRG (Diagnosis-Related Groups) system, which classifies medical cases and sets fixed tariffs, has reduced unnecessary patient costs and incentivized institutions to increase operational efficiency (Samkharadze, 2024).

Centralized purchases through the State Procurement Agency have reduced the cost of medicines and medical equipment. However, questions remain about quality control mechanisms for purchased goods and their distribution between institutions. In public-private partnerships aimed at attracting infrastructure investment, risks to long-term financial stability persist because contracts between the state and the private sector require clearly defined obligations for both parties.

3.3. Results of the survey of medical managers

The assessment of changes resulting from the introduction of foreign managers' experience is shown in Figure 1.

The survey results indicate that the impact of international management practices is perceived as gradual rather than revolutionary. 44.6% of respondents reported minor changes, suggesting a gradual adaptation of foreign approaches without drastic shifts in institutional structures or daily activities. 33.2% of respondents noted substantial reforms, indicating the presence of organizations in which international practices had a significant influence. This may reflect the active participation of foreign managers in transformation processes or the availability of specific programs focused on implementing international standards. 15.6% of managers did not notice any changes, which may be due to a lack of reforms within their institutions or to management's lack of involvement in adapting to new approaches. 6.5% of respondents found it difficult to answer, which may indicate ambiguity in the perception of changes or a lack of clear information about ongoing reforms. There is international influence on management approaches in Georgian healthcare, but its extent varies depending on the degree of integration of foreign experience within specific institutions.

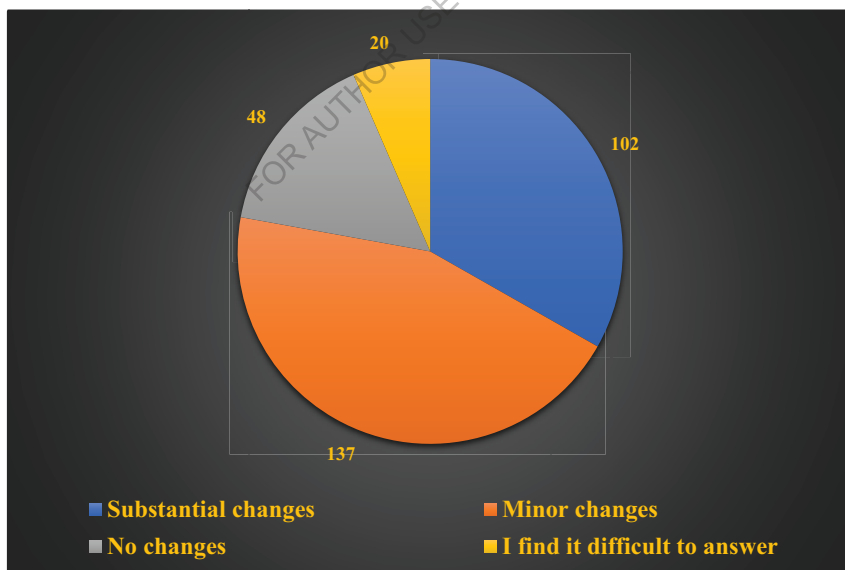


Figure 1. Distribution of respondents' responses to the question about changes in management approaches after the introduction of the experience of foreign managers
Source: compiled by the authors.

Using methods typical of foreign medical organizations has become common but not widespread (Figure 2).

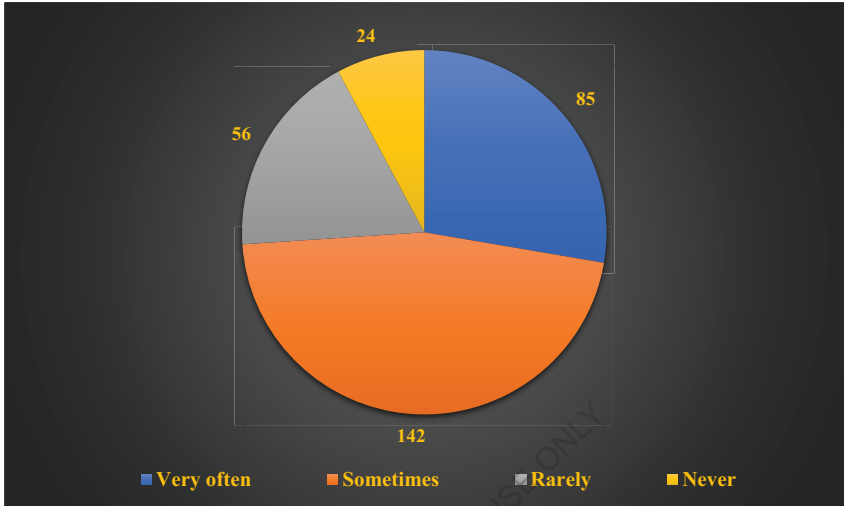


Figure 2. Distribution of respondents' replies to the question about the frequency of using methods and approaches typical of foreign medical organizations
Source: compiled by the authors.

Respondents (46.3%) often stated that such approaches are used in their institutions only occasionally, suggesting selective implementation of specific controls rather than a comprehensive adaptation of international standards. 27.7% of the survey participants stated that foreign methods are often used, possibly due to foreign managers in their institutions or programs focused on management reform based on international models. Thereby, 18.2% indicated that such approaches are rarely used, and 7.8% noted their complete absence. The data obtained indicated the presence of barriers preventing the widespread introduction of foreign practices. Possible reasons include staff resistance, a lack of resources to adapt to new standards, and the incompatibility of some international methods with local realities. That is, despite the influence of foreign experience, its integration into Georgian medical institutions remains heterogeneous, and the degree of implementation varies greatly depending on the management features in specific organizations.

The influence of specialists with foreign education on management styles in medical institutions in Georgia (Figure 3) is perceived primarily positively.

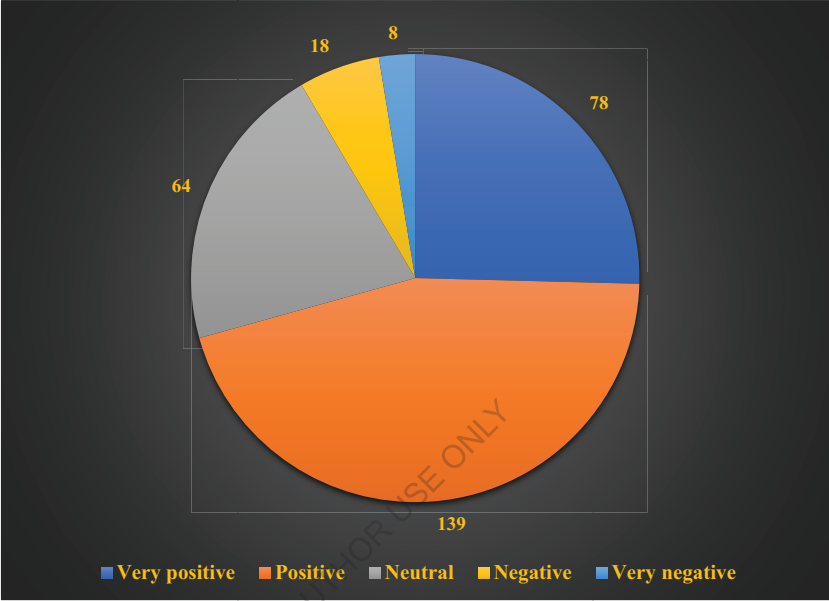


Figure 3. Distribution of respondents' responses to the question about the impact of the return of specialists with foreign education on management style
Source: compiled by the authors.

70.7% of respondents (the sum of “very positive” and “positive”) reported that specialists returning from abroad had a positive influence on their institutions' management style. This may indicate that such specialists bring new management practices, raise professional standards, and introduce modern working methods. The most likely factors driving this trend are specialists' familiarity with international management standards, their adaptation to digital solutions, and their focus on patient-centred healthcare models. 20.8% of respondents expressed a neutral attitude, which may indicate that the influence of specialists who have studied abroad is not felt across all aspects of their work or may manifest gradually. 8.5% of respondents noted a negative impact (the answers were “negative” and “very negative”).

Possible reasons may include differences in management approaches, generational conflict, inconsistencies between foreign methods and local realities, or

staff resistance to organizational change. Thus, the return of specialists with foreign education contributes to the modernization of management processes. However, the adoption of new approaches is uneven, and specific barriers may arise within the system.

Figure 4 shows an assessment of the impact of international management practices on resource planning and allocation in Georgian medical institutions.

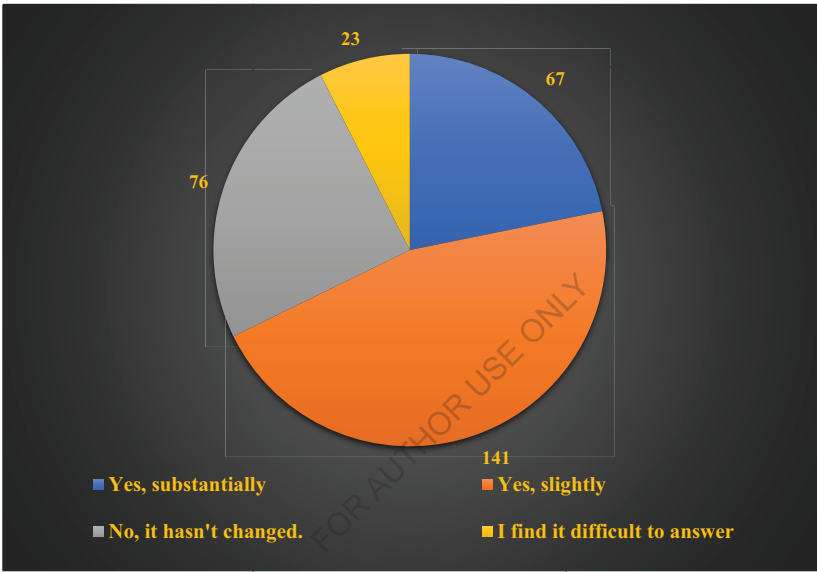


Figure 4. Distribution of respondents' answers to the question about the impact of international management practices on resource planning and allocation

Source: compiled by the authors.

Most of them (67.7%) noted that the approach to planning and allocating resources in their institutions has changed to some degree; that is, international practices are applied, but most often changes occur gradually and do not cover all levels of management. Analyzing the distribution of responses, it can be assumed that the institutions where the changes took place could focus on more flexible budget management, optimizing personnel decisions, and increasing transparency in the allocation of material resources. However, because a substantial number of respondents reported only partial or no changes, it can be concluded that the effect of introducing international practices remains limited and uneven. 24.8% of the survey participants

indicated that their institutions have not undergone changes in planning and resource allocation, which may indicate resistance to reforms, a lack of initiative from management, or a weak influence of international management models on practical processes.

The impact of international practices on the economic efficiency of medical institutions in Georgia (Figure 5) was positive, as indicated by managers.

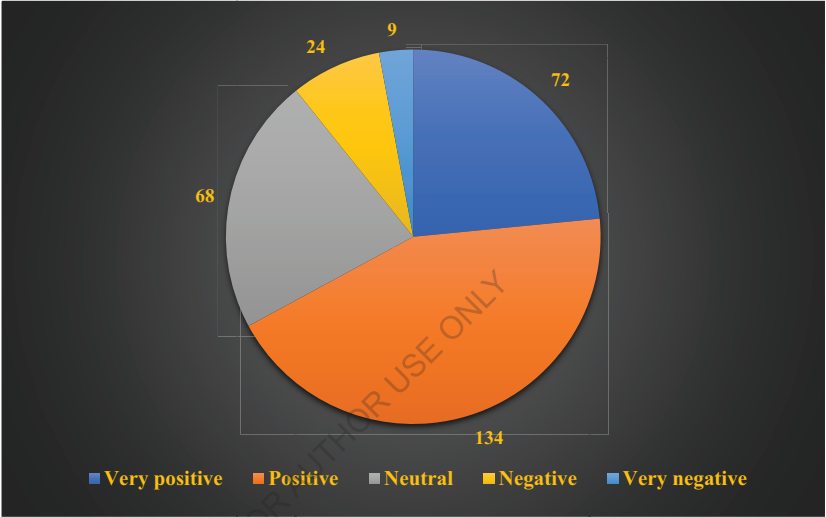


Figure 5. Distribution of responses to the question about the impact of international practices on the economic efficiency of the institution

Source: compiled by the authors.

67.1% of respondents rated the impact of international practices on economic efficiency positively, suggesting that introducing foreign practices may help reduce costs, improve the quality of patient care, and make more rational use of resources. This aspect is especially noticeable in private clinics and institutions that actively adopt digitalization and business process optimization. 22.1% of respondents showed a neutral attitude, indicating either a lack of awareness of specific effects or that the expected economic improvements have not yet fully materialized. 10.7% of respondents noted the negative impact of international practices, which may be associated with additional costs of adapting to new techniques, difficulties integrating

foreign standards, or staff resistance to change. The effectiveness of international practices depends on the specific conditions and level of adaptation in each institution; continued reforms and deeper integration of international approaches can further enhance the effectiveness of medical management in Georgia.

The survey results showed that the impact of international experience on the management of medical institutions in Georgia is perceived positively (Figure 6), with the most noticeable changes in quality of care and cost optimization.

High ratings for management aspects, such as improving the quality of care (64.5%) and optimizing costs (53.4%), may indicate medical institutions' desire to align with international standards to improve medical care processes and increase operational efficiency. This may be due to the introduction of modern protocols, digital solutions for patient care, and stricter cost controls. 47.9% of respondents reported increased staff efficiency, which may reflect the effects of the introduction of new management models, training, and employee professional development. The improvement in financial performance (35.5%) was mentioned less frequently, which may indicate difficulties in adapting to new economic strategies or that improvements in staff quality and efficiency have not yet led to a substantial increase in institutions' income.

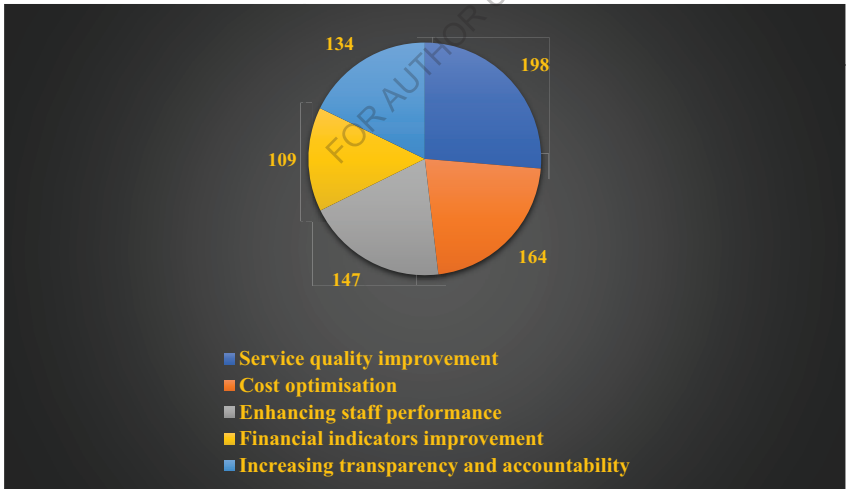


Figure 6. Distribution of responses to the question about the impact of international experience on the management of medical institutions in Georgia
Source: compiled by the authors.

Regarding the impact of international experience on the qualifications of medical managers, most respondents noted positive changes (Figure 7).

70.7% of respondents reported that managers' qualifications in their institutions have improved to some extent. Thus, the introduction of international practices has contributed to the professional development of senior management, probably through educational programs, training, and the exchange of experience with foreign specialists. An exceptionally substantial increase in qualifications (26.4%) may be typical for institutions that actively work with international partners or adapt foreign management standards. 22.1% of respondents did not notice any changes in managers' qualifications, which may be due to insufficient management involvement in adapting new methods or to the fact that the approaches used do not require a radical change in competencies. 7.2% of respondents reported a decrease in qualifications, which may be due to the difficulty of integrating new management approaches, staff unpreparedness, or resistance to change. The survey data confirmed that international experience positively affects medical managers' competence, but the process is not always straightforward. Additional educational initiatives may be required to bridge the gap between traditional and new management models and maximize their impact.

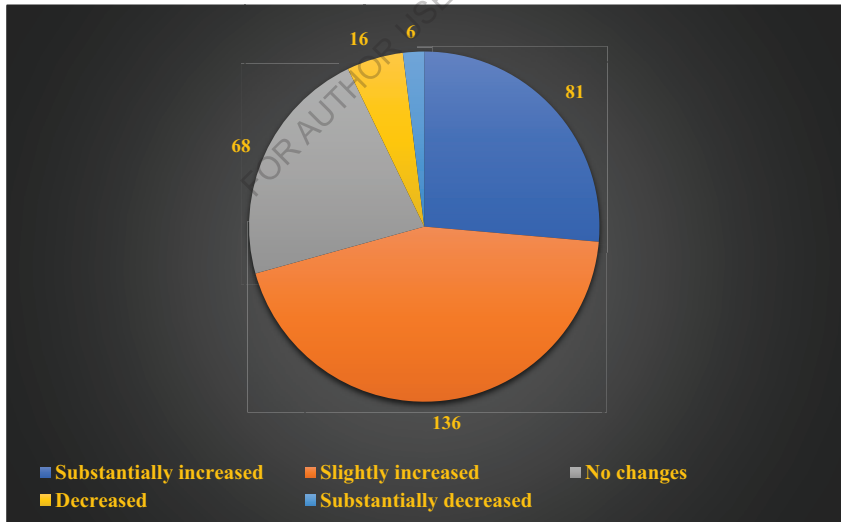


Figure 7. Distribution of respondents' responses to the question of changes in managers' qualifications after the introduction of new management methods
Source: compiled by the authors.

An analysis of the open issues showed that the introduction of international management methods had a substantial impact on the internal organization of medical institutions. It was noted that the changes primarily affected interdepartmental communication, responsibility sharing, and strategic planning. In some cases, there was an increase in the formalization of work processes, which contributed to a clearer structuring of staff responsibilities and improved the efficiency of interdepartmental interaction. However, adapting new practices has not been smooth in all institutions. In some organizations, difficulties arose due to employee resistance and insufficient adaptation of international methods to local realities.

Most respondents cited the introduction of digital solutions, standardized treatment protocols, or quality management methods as the most beneficial international practices. In particular, the transition to a more transparent accounting and reporting system is well-received, enabling the maximization of staff time and improved cost control. The difficulties were caused by management methods that assume a high degree of employee independence in decision-making, since such a management model requires a work culture different from the traditional hierarchical system.

The return of specialists with foreign education also played an important role in transforming management approaches. In institutions where such specialists hold key positions, there is accelerated adoption of international standards, the development of educational initiatives for staff, and the introduction of new approaches to workflow organization. However, it was noted that knowledge acquired abroad cannot always be applied in the Georgian healthcare system without adapting to local conditions, which requires flexibility.

When asked about ways to improve the process of implementing international experience, respondents pointed to the need for a smoother transition, allowing time for staff training and adapting new methods to the specifics of each institution. The proposals also included creating a platform for exchanging experiences among medical managers, regular educational programs, and greater support from government agencies in financing and implementing reforms.

The survey results showed that the introduction of international management practices has impacted the economic performance of medical institutions. However, the extent of these changes varies with the level of adaptation and the organization's willingness to reform. The main factors contributing to cost reduction include the digitalization of processes, the optimization of expenditure items, and the standardization of procedures. The most significant economic effect was observed in institutions that implemented electronic document management systems, automated

inventory management, and financial flow control methods, reducing unjustified spending and increasing spending transparency.

Some respondents also noted that adapting international procurement and contract management standards has led to lower costs by centralizing procurement procedures, increasing supplier competition, and improving logistics. In some cases, administrative costs could be reduced by redistributing responsibilities and eliminating duplicate functions. The increase in income can be attributed to improved quality of care and more efficient human resource management, which have led to increased patient flow at several institutions, especially in the private sector.

However, implementing international methods is accompanied by several substantial obstacles. One of the critical problems was staff resistance, especially among employees accustomed to the traditional management system. New approaches often require a review of work responsibilities, professional development, and adaptation to more flexible but demanding standards. The lack of manager training also hindered the effective implementation of changes, as not all managers had sufficient competence to work within new management models.

Financial constraints also remain an important factor: although many changes aim to reduce costs, their initial implementation requires investment, for example, in staff training, software procurement, or internal process reorganization. For some institutions, these costs may be high, slowing down or even stopping the implementation of international standards. In addition, formal regulatory requirements do not always facilitate the introduction of new methods; rather, they create additional bureaucratic barriers. Thus, international management methods can positively affect the financial performance of medical institutions. However, their implementation requires technical and administrative adaptations, overcoming resistance within the system, and sufficient funding to ensure a successful transformation.

4. Discussion

The study examined the management of medical institutions, healthcare financing, and the implementation of international management practices in Georgia. The analysis enabled the identification of the strengths and weaknesses of the current system, the determination of the roles of the private sector and government regulation, and the examination of the impact of digitalization and innovative solutions on healthcare effectiveness. The survey of medical managers found that integrating international experience brings positive changes, but administrative restrictions, financial difficulties, and staff shortages have hindered its implementation. An important result of the study was the understanding that healthcare system reform

requires an integrated approach combining strategic planning, institutional changes, and the adaptation of best international practices.

Although healthcare financing in Georgia combines elements of government regulation and market mechanisms, the introduction of universal health insurance programs and the attraction of private investment leave the system vulnerable to economic fluctuations and imbalances in resource allocation. One of the challenges of the existing healthcare system is the requirement that patients pay out of pocket, which increases the financial burden on households and creates uneven access to medical services. This approach creates a risk of deterioration in the health of vulnerable population groups. It increases the likelihood that some citizens will postpone or refuse medical care altogether due to financial barriers. In the long term, this may increase morbidity and the burden on the healthcare system. Comparison with the findings of M. Di Fusco et al. (2021) and M. Barati and H. Fariditavana (2022) showed parallels between the financial instability of the Georgian system and the problems of financing healthcare in the United States of America. As in Georgia, the burden of treatment costs is unevenly distributed in the United States, and low-income patients face limited access to medical care. According to Di Fusco et al. (2021), the high private spending on medical services increases the burden on insurance programs and public funds, especially during crises such as the COVID-19 pandemic. M. Barati and H. Fariditavana (2022) pointed out that healthcare financing based on private insurance exacerbates social inequality and makes the system less sustainable. Georgia, being in the process of reform, is facing similar challenges. Without a sustainable mechanism for redistributing costs and protecting socially vulnerable groups, its healthcare system risks becoming even more fragmented and financially unstable.

The development of Georgia's healthcare system requires innovative solutions, but several structural and economic barriers have constrained its implementation. Digitalization of medical services can be one of the most effective ways to overcome existing barriers by increasing the system's accessibility and transparency. Introducing electronic medical records, online consultations, and automated patient management systems can reduce administrative costs and improve coordination between medical institutions. However, the success of these transformations depends not only on technical equipment but also on the staff's willingness to adapt to new technologies. With insufficient digital literacy among doctors and administrative staff, innovation can slow processes rather than optimize them. Moreover, without a precise financing mechanism, digitalization can become another expense, increasing the system's financial burden. The problems of healthcare modernization in Georgia largely mirror those typical of other developing countries, as confirmed by M.G. Katoue et al. (2022) and S.C. Ifeagwu et al. (2021). As in the Middle East and African countries, the

Georgian healthcare system depends on government funding, which limits its flexibility in modernization. M.G. Katoue et al. (2022) highlighted the potential of a public-private partnership as a solution for Georgia, enabling it to attract additional investment in the sector's digitalization. A study by S.C. Ifeagwu et al. (2021) demonstrated that the lack of sustainable financing slows innovation and limits access to health services. Without a long-term strategy and cost-control mechanisms, digital reforms risk becoming fragmented and failing to achieve the expected improvement in the quality of medical care.

Limited digitalization in the Georgian healthcare system creates additional barriers to managing medical facilities and access to medical care. Although steps have been taken in the country to introduce electronic medical records and automated systems, their use remains fragmented and does not cover all medical institutions. The main reasons are the lack of funding and a comprehensive digital transformation strategy, which make it difficult to create a unified information infrastructure. In addition, the low level of digital literacy among medical personnel complicates the introduction of new technologies. As a result, coordination between institutions remains ineffective, the administrative burden on staff remains high, and patients continue to face bureaucratic difficulties in receiving medical care. Analyzing the situation in Georgia alongside the reforms in Saudi Arabia under the Vision 2030 program reveals substantial differences in approaches to digitalization. R. Rahman and H.M. Al-Borie (2020) found that in Saudi Arabia, reforms focused on private investment and public-private partnerships, which substantially accelerated the implementation of digital solutions and expanded their reach. In Saudi Arabia, digitalization is a strategic measure to reduce administrative costs and increase efficiency. In contrast, in Georgia, this process is more point-based and lacks a structured financing model. Without a review of approaches to investment and the management of digital reforms, Georgia risks lagging in the healthcare system's technological development, which will continue to create barriers to medical care for the population.

Reforms in the Georgian healthcare system affected the management structure of medical institutions, the degree of managerial autonomy, and the allocation of financial resources, thereby affecting the system's overall sustainability. The changes affected the level of autonomy of medical institutions: the private sector received more opportunities for self-government, while public clinics remained under the strict control of the Ministry. This redistribution of authority has affected the speed of decision-making, resource allocation, and infrastructure modernization, and created new challenges in coordinating the system. There are still risks of inconsistency across levels of government, as the lack of a unified mechanism for integrating public and

private structures leads to uneven resource distribution and gaps in the quality of medical services. Moreover, limited budgetary capacity has negatively affected Georgia's reliance on private capital. However, without a clearly defined strategy for partnership between the state and business, there is a risk that reforms will be fragmented and unsustainable in the long term. The problem of uneven distribution of resources and limited insurance coverage was established in the study by R. Kumar and A. Duggirala (2021). The authors determined that, like the Georgian system, India's health insurance system does not cover all citizens and remains unbalanced. According to L. Petersson et al. (2022), introducing digital solutions requires technology and substantial institutional changes. The Swedish experience has shown that, without adapting work processes and training professional personnel, technological innovations can encounter resistance from doctors. Thus, reforms in Georgia must account for both the technical aspects of the changes and their organizational consequences to avoid the problems other countries have already faced.

The management of Georgia's healthcare system is undergoing a period of adaptation, during which the integration of international experience is instrumental. The survey of medical managers found that introducing foreign management practices has positively impacted institutions' work. However, this process is uneven: some respondents noted improvements in strategic planning and resource allocation, but barriers related to staff resistance and the incompatibility of some foreign methods with local realities persist. Introducing new approaches requires flexibility, adaptation to local conditions, and additional training for managers since not all managers have the necessary competence to work in a changing environment. The development of interdepartmental cooperation has become an important factor, as the fragmentation of the healthcare system hinders coordination and increases institutional inefficiency. According to H.B. Lyng et al. (2021), adaptive leadership models have proven effective in times of crisis. In Norway, management flexibility and digital technologies have mitigated the effects of staff shortages, which indicates the potential of such solutions for the Georgian healthcare system. However, the main difference is that in Norway, these changes have become part of strategic planning, while in Georgia the introduction of international management approaches is more targeted and may face systemic barriers: while Norwegian managers have actively used telemedicine and digital tools to optimise processes, in Georgia, these technologies remain poorly integrated, which reduces the potential for rapid response to challenges.

The reviewed studies have confirmed the importance of a balanced approach to managing medical institutions and healthcare financing. However, the mechanisms for effectively combining private and public initiatives, the impact of digitalization on the system's long-term sustainability, and ways to overcome staff resistance to reforms

remain insufficiently examined. In addition, the question remains which management models enable optimal adaptation of international experience to the specifics of the national health system.

5. Conclusions

The study examined the specifics of healthcare management in the EU, Great Britain, and Georgia, as well as the impact of international experience on the Georgian system. An analysis of the management structures of medical institutions showed that EU countries use different approaches: a centralized model in which the state controls hospitals, and a decentralized model in which medical institutions have substantially more autonomy, supported by insurance funds. Georgia has a mixed system: strict control remains in public hospitals, while managers in the private sector have greater decision-making freedom. This means that the Georgian model combines the advantages of centralized control and the flexibility of market mechanisms, but requires more explicit regulation to ensure balanced management.

In the context of the economic component of medical management, the EU experience demonstrated that various financing models, from Beveridgean to Bismarckian, can ensure the system's sustainability. Georgia partially compensated for the previous model's shortcomings by implementing the State Universal Health Care program. However, a substantial share of the costs was borne by citizens, creating financial barriers for the population and limiting access to medical care. The study confirmed that the Georgian system will remain vulnerable to economic challenges without further reform of the financing mechanism. Digitalization of healthcare has become one of the most substantial factors in improving system efficiency in leading EU countries. It enabled substantial success by introducing electronic medical records and automated resource management systems. Despite progress in this direction, Georgia faces infrastructure challenges and resistance to change, which complicate the implementation of digital solutions.

The results of the medical manager's survey provided a deeper understanding of perceptions of international experience within the Georgian healthcare system. The majority of respondents noted the positive impact of foreign methods on the management of institutions, especially in terms of improving the quality of service (64.5%), cost optimization (53.4%), and professional development of management (47.9%). However, difficulties were also identified: 44.6% of study participants reported that the changes in their institutions were only partial, while 15.6% reported no impact. Among the identified barriers, the lack of staff training for new working methods, the difficulties of integrating international standards into existing processes, and insufficient funding for full implementation were most often cited. Implementing

reforms requires a systematic approach that will eliminate administrative obstacles and ensure the long-term sustainability of changes.

The study confirmed that international experience can improve the effectiveness of healthcare management in Georgia. However, its successful implementation is possible only if national characteristics and an integrated approach to system reform are taken into account.

The limitation of this study was the inability to fully assess the long-term effects of the introduction of international management practices, as the adaptation process continues and requires further monitoring. Future research may focus on the impact of digitalization on Georgian healthcare, including the effectiveness of electronic medical records, the automation of management processes, and the use of artificial intelligence in decision-making. Further review of these aspects will increase the transparency and efficiency of the healthcare system, optimize resource use, and reduce administrative barriers, leading to more affordable, high-quality medical care for the population.

References

1. Bach, T. 2022. Administrative autonomy of public organizations. In: Farazmand, A. (ed.), *Global Encyclopedia of Public Administration, Public Policy, and Governance* (pp. 269-277). Cham: Springer. https://doi.org/10.1007/978-3-030-66252-3_143
2. Barati, M., Fariditavana, H. 2022. Income and healthcare financing system in the United States: an asymmetric analysis. *Journal of Economic Studies*, 49(5), 809-820. <https://doi.org/10.1108/JES-12-2020-0592>
3. Barr, J., & Dowding, L. 2022. *Leadership in Health Care*. Los Angeles: Sage Publications. <https://www.torrossa.com/en/resources/an/5409523>
4. Bertram, M.Y., Lauer, J.A., Stenberg, K., Edejer, T.T.T. 2021. Methods for the economic evaluation of health care interventions for priority setting in the health system: An update from WHO CHOICE. *International Journal of Health Policy and Management*, 10(11), 673-677. <https://doi.org/10.34172/ijhpm.2020.244>
5. Capano, G., Lippi, A. 2021. Decentralization, policy capacities, and varieties of first health response to the COVID-19 outbreak: Evidence from three regions in Italy. *Journal of European Public Policy*, 28(8), 1197-1218. <https://doi.org/10.1080/13501763.2021.1942156>
6. Chanturidze, T., Ugulava, T., Duran, A., Ensor, T., Richardson, E. 2009. Georgia: Health system review. *Health Systems in Transition*, 11(8), 1-116. https://www.researchgate.net/publication/285717874_Georgia_Health_System_Review#pf2d

7. Civil Protection Department. 2025. *National Health Service*.
<https://www.protezionecivile.gov.it/en/approfondimento/national-health-service/>
8. Cleverley, W.O. 2024. *Essentials of Health Care Finance*. 9th edition. Burlington: Jones & Bartlett Learning. https://www.jblearning.com/catalog/productdetails/9781284203783?srsltid=AfmBOoqMoFhked7WtzVS_otZOq_V6nFLUANWGbKCJ9QdHhuYsqFXijdC#productInfo
9. Di Fusco, M., Shea, K.M., Lin, J., Nguyen, J.L., Angulo, F.J., Benigno, M., Malhotra, D., Emir, B., Sung, A.H., Hammond, J.L., Stoychev, S., Charos, A. 2021. Health outcomes and economic burden of hospitalized COVID-19 patients in the United States. *Journal of Medical Economics*, 24(1), 308-317.
<https://doi.org/10.1080/13696998.2021.1886109>
10. European Database on Medical Devices. 2017. *EUDAMED database*.
<https://ec.europa.eu/tools/eudamed/#/screen/home>
11. European Medicines Agency. 2025. *What we do*.
<https://www.ema.europa.eu/en/about-us/what-we-do>
12. European Union. 2005. *Directive 2005/36/EC of the European Parliament and of the Council of 7 September 2005 on the recognition of professional qualifications (Text with EEA relevance)*. <https://eur-lex.europa.eu/eli/dir/2005/36/oj/eng>
13. European Union. 2011. *Directive 2011/24/EU of the European Parliament and of the Council of 9 March 2011 on applying patients' rights in cross-border healthcare*. <https://eur-lex.europa.eu/eli/dir/2011/24/oj/eng>
14. European Union. 2024. *European Health Data Space*.
https://health.ec.europa.eu/ehealth-digital-health-and-care/european-health-data-space_en
15. European Union. 2025a. *eHealth: Digital health and care*.
https://health.ec.europa.eu/ehealth-digital-health-and-care_en
16. European Union. 2025b. *Signing ceremonies for the Joint Procurement Agreement*.
https://health.ec.europa.eu/health-security-and-infectious-diseases/preparedness-and-response-planning/signing-ceremonies-joint-procurement-agreement_en
17. Federal Ministry of Health, 2024a. *History of Statutory Health Insurance*.
<https://www.bundesgesundheitsministerium.de/themen/krankenversicherung/grundprinzipien/geschichte.html>
18. Federal Ministry of Health, 2024b. *Tasks and Organization of Statutory Health Insurance*.
<https://www.bundesgesundheitsministerium.de/themen/krankenversicherung/grundprinzipien/aufgaben-und-organisation-der-gkv.html>

19. Folland, S., Goodman, A.C., Stano, M., Danagouliau, S. 2024. *The economics of health and health care* (9th ed.). New York: Routledge.
<https://www.taylorfrancis.com/books/mono/10.4324/9781003308409/economics-health-health-care-sherman-folland-allen-goodman-miron-stano-shooshan-danagouliau>
20. Geerts, J.M., Kinnair, D., Taheri, P. 2021. Guidance for health care leaders during the recovery stage of the COVID-19 pandemic: A consensus statement. *JAMA Network Open*, 4(7), e2120295.
<https://doi.org/10.1001/jamanetworkopen.2021.20295>
21. Greer, S.L. 2021. Health, federalism, and the European Union: lessons from comparative federalism about the European Union. *Health Economics, Policy and Law*, 16(1), 90-103. <https://doi.org/10.1017/S1744133120000055>
22. Greer, S.L., Rozenblum, S., Falkenbach, M., Löblová, O., Jarman, H., Williams, N., Wismar, M. 2022. Centralizing and decentralizing governance in the COVID-19 pandemic: The politics of credit and blame. *Health Policy*, 126(5), 408-417.
<https://doi.org/10.1016/j.healthpol.2022.03.004>
23. Harrison, R., Fischer, S., Walpola, R. L., Chauhan, A., Babalola, T., Mears, S., Le-Dao, H. 2021. Where do models for change management, improvement, and implementation meet? A systematic review of the applications of change management models in healthcare. *Journal of Healthcare Leadership*, 13, 85-108.
<https://www.tandfonline.com/doi/full/10.2147/JHL.S289176>
24. Ifeagwu, S.C., Yang, J.C., Parkes-Ratanshi, R., Brayne, C. 2021. Health financing for universal health coverage in Sub-Saharan Africa: a systematic review. *Global Health Research and Policy*, 6(8). <https://doi.org/10.1186/s41256-021-00190-7>
25. Jiménez-Rubio, D. 2022. Health system decentralization: Creating as many problems as it solves? *International Journal of Health Policy and Management*, 12, 7432. <https://doi.org/10.1001/10.34172/ijhpm.2022.7432>
26. Jorbenadze, A. Verulava, T. 2022. These were the first steps in developing public health in independent Georgia. *Economics & Business*, 1, 184.
https://openurl.ebsco.com/EPDB%3Aagd%3A7%3A33671831/detailv2?sid=ebsco%3Aplink%3Ascholar&id=ebsco%3Aagd%3A156920867&crl=c&link_origin=scholar.google.com
27. Katoue, M.G., Cerda, A.A., García, L.Y., Jakovljevic, M. 2022. Healthcare system development in the Middle East and North Africa: Challenges, endeavors, and prospective opportunities. *Frontiers in Public Health*, 10, 1045739.
<https://doi.org/10.3389/fpubh.2022.1045739>
28. Kosklin, R., Lammintakanen, J., Kivinen, T. 2022. Knowledge management effects and performance in health care: a systematic literature review. *Knowledge*

- Management Research & Practice*, 21(4), 738-748.
<https://doi.org/10.1080/14778238.2022.2032434>
29. Kumar, R., Duggirala, A. 2021. Health insurance as a healthcare financing mechanism in India: Key strategic insights and a business model perspective. *Vikalpa*, 46(2), 112-128. <https://doi.org/10.1177/02560909211027089>
 30. Legislative Herald of Georgia. 2004. *On Approval of the Public Health Department Regulations of the State Sub-Institution Ministry of Labor, Health, and Social Protection of Georgia*.
<https://matsne.gov.ge/ka/document/view/58654?publication=0>
 31. Lyng, H.B., Ree, E., Wibe, T., Wiig, S. 2021. Healthcare leaders use innovative solutions to ensure resilience in healthcare during the COVID-19 pandemic: A qualitative study in Norwegian nursing homes and home care services. *BMC Health Services Research*, 21, 878. <https://doi.org/10.1186/s12913-021-06923-1>
 32. Netherlands Tax Authorities. 2024. *Health Insurance Act*.
https://www.belastingdienst.nl/wps/wcm/connect/bldcontentnl/belastingdienst/prive/werk_en_inkomen/zorgverzekeringswet/
 33. Official State Gazette Agency. 1986. *Law 14/1986, of April 25, General Health*.
<https://www.boe.es/buscar/act.php?id=BOE-A-1986-10499>
 34. Owusu, P.A., Sarkodie, S.A., Pedersen, P.A. 2021. Relationship between mortality and health care expenditure: A sustainable assessment of the health care system. *PLoS ONE*, 16(2), e0247413.
<https://doi.org/10.1371/journal.pone.0247413>
 35. Petersson, L., Larsson, P., Nygren, J.M., Nilsen, P., Neher, M., Reed, J.E., Tyskbo, D., Svedberg, P. 2022. Challenges to implementing artificial intelligence in healthcare: A qualitative interview study with healthcare leaders in Sweden. *BMC Health Services Research*, 22, 850. <https://doi.org/10.1186/s12913-022-08215-8>
 36. Presidency of the Council of Ministers. 2024. *Decree-Law No. 54/2024, of September 6. Official Gazette, Series I, No. 173/2024*.
<https://diariodarepublica.pt/dr/detalhe/decreto-lei/54-2024-887091776>
 37. Rahman, R., Al-Borie, H.M. 2020. Strengthening the Saudi Arabian healthcare system: Role of Vision 2030. *International Journal of Healthcare Management*, 14(4), 1483-1491. <https://doi.org/10.1080/20479700.2020.1788334>
 38. Samkharadze, T. 2024. *Impact of the Diagnosis-Related Group (DRG) Financing Method on the Georgian Healthcare System*. Tbilisi: Ilia State University.
<https://eprints.iliauni.edu.ge/12818/>
 39. State Procurement Agency. 2025. *Functions*.
<https://procurement.gov.ge/ka/page/features>

40. Swedish Parliament. 2017. *Health and Medical Care Act (2017:30)*. <https://goo.su/Z1LKN>
41. Tabidze, D., Baramidze, L., Chkheidze, T. 2022. Human resources (HR) management and administration in the hospital sector. *Experimental and Clinical Medicine Georgia*, 7. <https://doi.org/10.52340/jecm.2022.07.11>
42. Terkamo-Moisio, A., Karki, S., Kangasniemi, M., Lammintakainen, J., Häggman-Laitila, A. 2021. Towards remote leadership in health care: Lessons learned from an integrative review. *Journal of Advanced Nursing*, 78(3), 595-608. <https://doi.org/10.1111/jan.15028>
43. The King's Fund. 2024. *The NHS budget and how it has changed*. <https://www.kingsfund.org.uk/insight-and-analysis/data-and-charts/nhs-budget-nutshell>
44. Tountas, G., Kyriopoulos, G., Lionis, C., Nektarios, M., Souliotis, K., Karanikolos, G., Filalithis, T. 2020. *The New ESY: Reorganization of the National Health System*. Athens: National and Kapodistrian University of Athens (EKPA). <https://goo.su/0yvOctN>
45. Transparency International Georgia. 2013. *What to know about the universal health care state program: Frequently Asked Questions*. <https://www.transparency.ge/ge/jandatsvis-sakhelmtsipo-programa-xshirad-dasmuli-kitxvebi>
46. Vampa, D. 2021. COVID-19 and Territorial Policy Dynamics in Western Europe: Comparing France, Spain, Italy, Germany, and the United Kingdom, *The Journal of Federalism*, 51(4), 601-626. <https://doi.org/10.1093/publius/pjab017>
47. Verulava, T. 2023. Reform of the health insurance system model in Georgia. *Economics & Business*, 1, 112. <https://goo.su/ArdVHgc>
48. Willocks, K., Moralee, S. 2021. Reframing healthcare leadership: From individualism to leadership as collective practice. In: Kislov, R., Burns, D., Mørk, B.E., Montgomery, K. (eds.), *Managing Healthcare Organisations in Challenging Policy Contexts. Organizational Behavior in Healthcare* (pp. 229-253). Cham: Palgrave Macmillan. https://doi.org/10.1007/978-3-030-81093-1_11

DETERMINANTS OF STRUCTURAL CHANGE IN TRADE FLOWS

Imeda Paksadze

Assistant Professor of Batumi Navigation University

Iago Beridze

Associate Professor of Batumi Navigation University

Givi Bakradze

Associate Professor of Batumi Navigation University

Abstract. The article discusses the theory and practice of modern international trade liberalization, including within the framework of the World Trade Organization, which requires serious correction, a differentiated approach, and more attention to the interests of developing countries and countries with economies in transition.

Keywords: trade flows, structure of international trade flows, trade turnover, export.

Introduction

International trade consists of two counterflows of goods - exports and imports, which are characterized by the trade balance and trade turnover.

Export is the sale of goods for delivery abroad. Import is the purchase of a product for delivery from abroad. The trade balance is the difference between the value of exports and imports ("net exports"). Trade turnover is the sum of the value of exports and imports.

Discussion

It is clear that exports are very profitable for countries. From 1950 to 1990, global gross domestic product increased 5 times (at constant prices), and exports of goods increased 11 times. During this period, manufacturing industries expanded 8-fold, and their exports increased 20-fold. During the last decade of the last century, GDP increased by 1/4, and world exports of goods doubled. As a result, the foreign trade quota, i.e., the dependence of all countries' economies on foreign trade, is calculated as the ratio of the value of foreign trade turnover to the value of world GDP. In 2022-24, these indicators (in constant prices) increased from 32 to 40% (Table 4).

Table 4. World exports of goods and services

Indicator	Value, billion \$			Average annual growth rate, %		
	2022	2023	2024	2022	2023	2024
Goods	7274	8907	9600	6	16	21
Services	1763	2125	2500	7	12	18

Let us consider some important features of global trade:

1. International trade acts as a substitute for international resource mobility - if human and material resources cannot move freely between countries, then the movement of goods and services effectively fills this gap.
2. Each country has its own currency, and this must be taken into account when carrying out export-import operations.
3. International trade is subject to strong political intervention and control.

Let us list the main incentives for export:

1. Use of excess capacity.
2. Reduction of the cost per unit of production.
3. Increasing profitability by increasing markup (the ability, under certain conditions, to sell our products at a higher profit abroad than domestically).
4. Distribution of sales risk.

The main incentives for import are:

1. Cheaper supply of goods or raw materials.
2. Expansion of the range.
3. Reducing the risk of interruption of supply of goods.

We can also identify certain obstacles to foreign trade:

- lack of knowledge about existing opportunities,
- lack of information about the trade mechanism;
- fear of risk;
- trade restrictions.

The structure of world trade reflects the changes in the economies of the participating countries and the process of globalization of economic life. The leading place in world exports is occupied by manufactured goods, the share of which reached 75% in 2023 (70% in 2020). Of these, machinery, equipment and transport vehicles account for about 40% (36% ten years ago), among which the most dynamic is office and telecommunications equipment - more than 13%, while the rate of trade in automotive products has stabilized at 9%. The next most important commodity item is mining products - 12% (14%), in which manganese ore occupies the main place. The

importance of agricultural products is still decreasing - less than 9% (against a base of 12%), as well as textiles and clothing - to 5% (against a base of 6%).

Since the beginning of the twentieth century, two “floors” have emerged in the structure of the world commodity market - the market for basic goods (fuel, mineral raw materials, agricultural products, timber) and the market for finished goods. The first type of goods was produced by developing and former socialist countries, which specialized in the export of resource- and labor-intensive goods. Out of 132 developing countries, 15 specialize in the export of oil, 43 in the export of mineral and agricultural raw materials.

The second “floor” is the prerogative of developed industrial and “post-industrial” countries. Modern international trade is an extensive, multi-level system. The lower floor - the market for basic goods - consists of agricultural and mining products. The middle floor - semi-finished products and labor-intensive finished products, i.e. low and medium-tech products (ferrous metallurgy, building materials, textiles and other light industry products). Medium-tech goods include machine tools, vehicles, basic chemical products, rubber and plastic products, and woodworking products.

The most dynamic sector of international trade in recent years is the exchange of goods in the “high-tech” or knowledge-intensive industries and non-material production sectors. This is the market for high-tech products, which today is decisive for the market of office and telecommunications equipment, electronics, electrical equipment, precision measuring instruments, space technologies, complex medical equipment, and pharmaceuticals.

The main trading powers, as before, are economically highly developed countries, primarily the USA, Germany, Japan, France and Great Britain.

The leadership of developed countries in international trade is maintained, first of all, by the export of high-tech products and related services. They account for almost 3/4 of world exports of these products, which amount to more than 1 trillion dollars in value.

The structure of international trade is usually considered in terms of its geographical distribution (geographical structure) and product content (commodity structure).

Many developing countries are still highly dependent on exports of the mining industry (75% of exports from the Middle East) and agriculture (from Latin America and Africa).

However, among developed countries there are examples of high dependence on commodity exports, which is explained by natural competitive advantages (60% of Norway's exports are oil and gas, Australia and Canada - ores and metals, while 60% of New Zealand's exports and 67% of Iceland's exports are agricultural - natural goods).

The largest volume of foreign trade transactions among transition countries is recorded in the countries of Central and Eastern Europe, although in general their share in international trade still remains very small (in 2023 - less than 4%).

The most modest position in the international trade system is occupied by the least developed, 50 poor countries, whose share in world exports is only 0.6%. The difference in incomes of these countries compared to developed and rich countries is about 1:150, and their constant marginalization is fraught with dangers that they bring to the process of world economic globalization.

A characteristic feature of world trade is the existence of a special price system - world prices. They are based on international production costs, which are based on the average world costs of economic resources for the production of this type of goods. International production costs are formed under the influence of those countries that are the main suppliers of this type of goods on the world market. In addition, the ratio of supply and demand for a given type of product on the world market has a significant impact on the level of world prices.

International trade is characterized by price diversity, that is, the presence of different prices for the same product. World prices vary depending on the time of year, location, terms of sale of goods and the specifics of the contract. In practice, world prices are taken to be the prices of large, systematic and stable export or import transactions concluded in certain centers of world trade by well-known firms - exporters or importers of the corresponding type of goods. For many goods (grains, cotton, rubber, etc.), world prices are determined as a result of trading on the world's largest commodity exchanges.

The international value is usually less than the national value of the corresponding goods, since the most competitive goods, that is, those produced at the lowest cost, are usually supplied to the world market. Other factors also influence world prices: the ratio of supply and demand, the quality of products and the state of the monetary sphere. In addition, long-term trends in the formation of world prices manifest themselves as a universal effect of the law of value on the world market.

To quantify the impact of foreign trade on the growth of the country's national income and GDP, a foreign trade multiplier model has been developed and is used in practice. Using it, the foreign trade multiplier model can also be calculated. At the same time, we will make an assumption about the possibility of independent influence of imports and exports on the development of the national economy of a country participating in foreign economic activity. The impact of imports in this case can be equated with consumption, and the impact of exports - with investments. Accordingly, the marginal propensity to consume in this case takes the form of the marginal

propensity to import: $c = m = M/Y$, and the marginal propensity to save takes the form of the marginal propensity to export: $s = x = X/y$ (according to Keynes).

In real life, exports and imports are interconnected. A country's imports are simultaneously exports to the counterparty state. Such interdependence significantly complicates the multiplier model, which must take into account the interaction of at least two countries to reflect real foreign trade relations.

The report, prepared by WTO experts, analyzes and statistics on world trade and global financial indicators and establishes its upward projections, as well as assesses the risks associated with modern geopolitical and financial instability. According to their forecast, trade growth, which gradually accelerated in 2024, despite regional conflicts, geopolitical tensions and previous fluctuations, will continue to accelerate.

In recent years, global trade has been affected by a combination of adverse factors, which have been collectively called a “polycrisis”. These factors include supply and demand shocks associated with the COVID-19 pandemic, supply chain disruptions and increased uncertainty in trade policies caused by the impact of geopolitical rivalry.

Despite these challenges, global trade has been remarkably resilient over the past four years. Thus, by the end of 2023, the volume of merchandise trade had grown by 6.3% compared to 2019. Commercial services also grew, their value increasing by 21% from 2019 to 2023. In 2023, the global value of US dollars in merchandise trade fell by 5% compared to the previous year (to \$24.01 trillion), but the decline was largely offset by strong growth in commercial services trade, which grew by 9% (to \$7.54 trillion). The decline in merchandise exports was partly due to falling prices for commodities such as oil and gas. At the same time, the growth in commercial services trade was driven by the resumption of international travel and the growth of digital services.

The risks to the recovery and development of international trade are mainly related to geopolitical tensions and uncertainty. The unfavorable trade environment that prevailed in 2023 is expected to improve somewhat in 2025 and 2026, supporting the growth of merchandise trade, which will create real income growth in emerging economies, which in turn will lead to an increase in the consumption of manufactured goods. The recovery in demand for tradable goods was already evident in 2024. This is driven by increased household consumption, which in turn is associated with improved income prospects. However, geopolitical tensions and political uncertainty may limit the extent of the trade recovery. While export growth should improve in many countries as external demand for goods increases, food and energy prices may remain subject to shocks stemming from geopolitical events.

Choosing the right pace to cut interest rates will also be a challenge for central banks in advanced economies, and any misstep could lead to financial instability in

2025. The recovery in trade could also be hampered by rising trade costs and uncertainty in international relations.

The sustainability of global trade is also being tested by disruptions to two of the world's main shipping routes, the Panama and Suez Canals. While global shipping costs had returned to pre-pandemic levels by mid-last year, container shipping rates have started to rise again.

The WTO also notes early signs of trade fragmentation, with exports and imports being redirected according to geopolitical conditions. Foreign direct investment (FDI) is also increasingly being channeled to countries considered friendly. According to the International Monetary Fund, foreign direct investment flows to developing and least developed countries are substantially lower for geographically more distant partners.

This sensitivity to geopolitical distance increased in 2018–2021 and is particularly noticeable in strategic sectors such as semiconductors, telecommunications equipment, equipment needed for the transition to a green economy, pharmaceutical ingredients, and critical minerals.

The impact of institutional factors is also important: political, economic, and financial globalization and liberalization. Until recently, the rapid growth of international trade was due to the processes of political, economic, and financial globalization and liberalization in the world. The intensification of global and regional spatiotemporal convergence is manifested in the creation of new political institutions and international organizations, in the increase in the pace of cross-border movement of labor, capital, information, in the further strengthening of the role of transnational companies. Transnational corporations, as the main operators of world trade, in the most remote and, perhaps, previously closed territories.

Let us consider the technical and technological factors of influence. Technical and technological factors have become accelerators (accelerators) of international trade: computerization and, in a broader sense, information and communication technologies (IT), automation, robotization, containerization of transport transport, new engineering and consulting technologies, services and services that have arisen on this basis. The widespread use of such technologies has led to a noticeable increase in labor and capital productivity, production efficiency, and a decrease in labor costs and production costs. Thus, innovations in transport technologies have led to significant structural changes in international transport and, consequently, in the entire world trade. If in 1970 the tanker fleet occupied the lion's share of maritime traffic (55% of total tonnage), by 2017 it had almost halved and amounted to 29.4%. Since 1980, the average annual rate of tanker use has been growing by only 1.4%, while dry bulk carriers have been growing by 4.6%. Container transport is the fastest growing segment, accounting for a CAGR of 8.1%.

Spatial factors. New large countries (China, India, the countries of the post-Soviet and post-socialist space, etc.) and regions (South-East Asia, East Asia, Asia-Pacific, Central and Eastern Europe, CIS, etc.) have appeared on the geographical map of the world, which have their own markets.

Organizational and managerial factors - include technological and production process control systems, marketing, logistics, management systems; systems for the full production cycle from the development of new products to the delivery of goods to the end user, etc.

Conclusion

Business models that include deep international production cooperation, production fragmentation, global value chains, public-private partnerships, personalization, online commerce.

National governments have taken an active part in protecting and promoting the interests of national companies in global industrial and commodity markets, whose activities can be considered as one-way support and incentive measures, thereby increasing the international competitiveness of national producers, primarily transnational companies and goods.

Governments have promoted foreign economic activity by pursuing targeted long-term policies, as well as by financing the construction and modernization of infrastructure facilities that serve foreign trade flows that are state-owned or fall within the direct responsibility of the state (roads and railways, airports, sea and river ports).

References:

1. Adam, N. R. (2023). Achieving a confidence interval for parameters estimated by simulation. *Management Science*, - V.29(№7.), - P.856-866.
2. Beograd J.C. The formal simulation theory from the user's point of view // ESC Conference. Aachen, 2023. - P. 112-117.
3. Beograd, J. C. (2023). The formal simulation theory from the user's perspective. *ESC Conference. Aachen*, (pp. - P. 112-117.). Bucharest, Romania.
4. Classification and related methods of data analysis // Editor Bock H. - Amsterdam: NORTH-HOLLAND, 2018. 749p.
5. CRRC-საქართველოს და ფონდი „პარტნიორობა საგზაო უსაფრთხოებისთვის“ . (2024, ივნისი). უსაფრთხო გადაადგილების შესაძლებლობები მგზავრებისთვის – პოლიტიკის დოკუმენტი. თბილისი: აღმოსავლეთ-დასავლეთის მართვის ინსტიტუტის (EWMI) ACCESS-ის პროექტის ფარგლებში; .

6. Gitolendia, B. (2018). “Ways of approximation and further compatibility of the Georgian transport system with the European and International Standards“. Tbilisi: Paata Gugushvili Institute of Tbilisi Iv.Javakhishvili State University.
7. Law A.M., Kelton D.W. Simulation modeling and analysis. N.Y.: McGraw-Hill, 2021.- 325p.
8. Mamrac S.A., Amer P.D. Estimating confidence intervals for simulations on a computer system // Simulation. 2020. - V.35, №6. - P.199-205.
9. *Statistics on Merchandise Trade. Annual Trade Data. World Trade Organization. Available at: https://www.wto.org/english/res_e/statis_e/merch_trade_stat_e.htm (accessed 29.02.2020)*
10. Tersine R.J. Principles of inventory and materials management, 4th ed. N.Y.: Elsevier North-Holland, 1994.
11. White House. (2024, January). Economic Report. *Together with the Annual Report of the Council of Economic Advisers*. D.C., Washington. Retrieved from https://obamawhitehouse.archives.gov/sites/default/files/docs/2017_economic_report_of_president.pdf
12. ასოცირების შესახებ შეთანხმება ერთის მხრივ, საქართველოსა და მეორეს მხრივ, ევროკავშირის და ევროპის ატომური ენერგიის გაერთიანებას და მათ წევრ სახელმწიფოებს შორის. (2014). <https://matsne.gov.ge/ka/document/view/2496959?publication=0>
13. ზღიაძე, მ. (2018). ავტოტრანსპორტი და მისი მომავალი. *ჟურნალი სოციალური ეკონომიკა 21-საუკუნის აქტუალური პრობლემები*, გვ. 47-49;.
14. გ. კვაშილაძე – „ევროსტანდარტები ბათუმის სატრანსპორტო სისტემაში“ ეკონომიკა – 2016;
15. გოგსაძე, გ. (2023). „*სივრცე, პოლიტიკა, იდენტობა*“. თბილისი. Retrieved from https://www.tsu.ge/data/file_db/faculty_social_political/sivrc-politika-identoba.pdf;
16. ზაზანაშვილი, ნ., & კალანდარაშვილი, ლ. (2015). საქართველოს ძეგლები. http://www.dzeglebi.ge/statiebi/istoria/saqartvelos_industiruli_memkvidreoba.htm
1
17. კვინიკაძე, გ. (2023). *გეოეკონომიკისა და ეკონომიკური გეოგრაფიის აქტუალური საკითხები*. თბილისი: თბილისის უნივერსიტეტის გამომცემლობა.

18. ლაშვი, ი. (2008). საქართველოს რკინიგზა პრობლემები და პერსპექტივები.
http://www.osgf.ge/files/news/news2008/RAILWAY_Final_Report_GEO_Zf7Q8OInf m.pdf
19. მასხულია მიხეილ. (2016). საქალაქო სატრანსპორტო მომსახურების განვითარების მიმართულებები. თბილისი: საქართველოს ტექნიკური უნივერსიტეტი.
20. ყილი, ჟ.-მ. (2015 წლის 12). თბილისის მდგრადი ურბანული ტრანსპორტის სტრატეგია.
[http://mdf.org.ge/storage/assets/file/documents%202016/murtazi/Strategic%20Paper%20Report%20PDF%20Geo\(18_03_2016\)/Strategic%20Paper%20Report%20PDF%20Geo.pdf](http://mdf.org.ge/storage/assets/file/documents%202016/murtazi/Strategic%20Paper%20Report%20PDF%20Geo(18_03_2016)/Strategic%20Paper%20Report%20PDF%20Geo.pdf)
21. საქართველოს მთავრობა. (2025). *სამთავრობო პროგრამა „მხოლოდ მშვიდობით, ღირსებით, კეთილდღეობით ევროპისკენ“*. თბილისი: საქართველოს პარლამენტი. Retrieved from https://www.gov.ge/files/90372_90372_536784_372256.pdf
22. ტ. ბოლქვაძე, et al. (2015). *სატრანსპორტო ლოჯისტიკა*. თბილისი: განათლების ხარისხის განვითარების ეროვნული ცენტრი.

MODERN NAVIGATION SYSTEMS AND THEIR ROLE IN INCREASING THE SAFETY OF MARINE TRANSPORTATION

Parmen Khvedelidze

Doctor of Transport, BNU Professor

Dursun Tsintsadze

Doctor of Transport, BNU Professor

Giorgi Kikvidze

Engineer of Water Transport Operation,

BNU Associate Professor;

Valerian Imnaishvili

Master of Maritime Law, Bachelor of Ship Management

Nino Beridze

Doctor of Education, Professor

Abstract. This study evaluated the economic and operational efficiency of maritime navigation systems worldwide, with a focus on Georgia's maritime sector to improve safety and reduce shipping costs. The analysis used simulation modeling based on hypothetical operational scenarios and was verified with data from industry reports. Results showed that global positioning systems (ROI of 150%, minimal implementation costs of \$10,000, and maintenance costs of \$1,000) and automatic identification systems (ROI of 120-125% with a 15-18% cost reduction) offered the highest economic efficiency. Satellite communication provided a balanced cost-benefit ratio (ROI of 110%, 14% cost reduction). Integrated bridge systems, while capable of reducing costs by 18%, were constrained by high implementation costs (\$100,000) and low adoption in Georgia (30%). In the Georgian context, automatic identification cut incidents by 20%, saving \$6,000 annually in insurance costs (ROI of 40%), while satellite communication reduced incidents by 15%, saving \$4,500 (ROI of 22.5%). Electronic chart systems and radar systems demonstrated moderate efficiency, but their use was limited by interface complexity and high training costs (\$5,000–\$12,000). The systems' vulnerability to cyberattacks highlighted the need for improved cybersecurity measures. The practical importance of these findings lies in creating recommendations for shipping companies and regulators that could be implemented by shipping firms, authorities, and educational institutions to modernize navigation infrastructure and train crews in Georgia's maritime sector.

Introduction.

Maritime transport remains a vital component of the global economy, accounting for up to 80% of international trade volumes. However, the rapid growth of the maritime industry has brought numerous challenges, from technical and navigational risks to environmental threats caused by increased shipping activity. In this context,

digital navigation systems play a crucial role in improving the safety and sustainability of maritime transport. Their integration into the maritime sector helps reduce accident risks, optimize routes, prevent pollution, and enable timely responses to dangers from both human and external factors.

Existing navigation solutions address not only technical issues; they also consider environmental, logistical, and strategic factors in maritime shipping. The study by N. P. Santos et al. [1] at the OCEANS 2024 conference examined unmanned maritime vehicles as platforms for hybrid navigation models. The authors emphasized that autonomous operations under high uncertainty require new navigation logics with sensor adaptability, spatiotemporal prediction, and multi-criteria decision-making, thereby reducing reliance on human input and enhancing the safety and reliability of navigation. Additional insights came from research on environmentally sustainable maritime technologies. X. Rao et al. [2] investigated methanol as an alternative fuel for marine engines, highlighting that using it requires updating navigation algorithms to account for new risks—storage, ignition, and emergencies. They stressed the importance of incorporating these factors into routing and traffic management systems, which directly impact navigation safety and environmental compliance.

J. Ma et al. [3] proposed a model to analyze causes of spontaneous vessel flooding using a network approach. They organized technical, organizational, and human factors influencing emergencies and identified potential escalation points. Their work emphasized the importance of understanding complex and loosely connected elements within the navigation system and the need to integrate such models into maritime safety management. M. Li et al. [4] evaluated the risk of damage to submarine cables caused by anchoring vessels. They developed a probabilistic model considering navigational behavior near critical infrastructure. The study highlighted the need for precise positioning and movement forecasts in port zones, where anchoring mistakes could lead to systemic communication and safety failures.

M. Zhang et al. [5] summarized advancements in AI integration, automation of navigation analysis, and multisensory data processing. They went beyond just reviewing technology, offering a conceptual framework to enhance maritime safety. Their work demonstrated how adaptive predictive algorithms and distributed control could mitigate navigational risks in dynamic maritime environments. The study provided a foundation for developing next-generation navigation systems focused on resilience, autonomy, and proactive incident prevention.

The safety of autonomous maritime systems relies on digital twins, sensory data, and AI algorithms, which reduce human error and allow adaptation to changing environments. D. Dagdilelis et al. [6] proposed a method of deep data fusion from cameras, radars, and lidars to improve environmental perception, lowering accident risks. Similarly, D. Menges & A. Rasheed [7] created a digital twin—an real-time virtual vessel model—to predict and prevent accidents, boosting the reliability of autonomous navigation in complex conditions. A new trend in developing intelligent

navigation systems involves using language models for control tasks. F. Ma et al. [8] developed the Navigation-GPT (Generative Pre-training Transformer) architecture—an adaptive system based on a Large Language Model (LLM) that interprets navigation scenarios and supports decision-making under uncertainty. Unlike traditional algorithms, this model considers context, command structure, and vessel behavior, offering flexibility and learning capability for the navigation system. This development opens avenues for moving from purely algorithmic control toward cognitive support for maritime operations.

In the context of increasing demands for the safety and sustainability of global maritime transport, Georgia acts as a strategically important transit country of the Middle Corridor. R. Mamuladze and G. Mamuladze [9] emphasized that the efficiency of Georgian maritime logistics directly affects the stability of global supply chains, stressing the need for digital modernization and port management automation. B. Gechbaia and A. Tsilosani [10] noted the potential of intermodal and container transport as the basis for Georgia's integration into international logistics networks, while also highlighting the lag in the use of modern navigation technologies. The development of navigation infrastructure in the country was viewed not only as an internal necessity, but also as a factor enhancing its role in the global maritime transport system.

Despite the existence of successful practices and universal solutions, significant gaps remained due to the uneven spread of modern technologies, especially in countries with developing maritime infrastructure (Georgia). The adaptation of these technologies in various geographical, economic, and institutional contexts required further research.

The purpose of this study was to comprehensively assess the economic and operational performance of existing maritime navigation systems on an international scale, taking into account the specific characteristics of Georgia's maritime sector, to justify the path to improved navigation safety and reduced shipping costs. To achieve this goal, the following objectives were set: to conduct a quantitative and comparative assessment of the economic efficiency of maritime navigation systems considering costs, ROI (Return on Investment), TCO (Total Cost of Ownership), and insurance returns in both global and regional (Georgian) contexts; to evaluate the impact of navigation technology implementation on shipping safety, taking into account the specifics of the Georgian navigation environment; to analyse the social applicability of the systems and to develop practical recommendations for the integration into the maritime industry, considering the Georgian context.

Materials and methods.

The study was conducted from June 2024 to April 2025 at the laboratory of the internationally accredited Batumi State Maritime Academy (BSMA). The primary focus was on the comparative analysis of the Automatic Identification System (AIS),

Electronic Chart Display and Information System (ECDIS), Global Positioning System (GPS), Global Maritime Distress and Safety System (GMDSS), International Maritime Satellite Organization (Inmarsat), radar systems, and Integrated Bridge System (IBS). Simulation modelling was carried out in four stages using a custom model that combined a probabilistic approach and empirical input parameters. It aimed to quantitatively assess the impact of navigation technologies on safety, operational costs, and practical applicability in both international and regional (Georgian) contexts.

At the first stage, a baseline scenario of vessel operation without the implementation of automated navigation systems was modelled. The input parameters used included: vessel type — standard medium-tonnage cargo fleet (10,000-50,000 Deadweight Tonnage), most commonly used in international and Georgian practice; statistically relevant visibility values (0.5-10 miles); traffic density and hydrometeorological conditions, based on reports by Inmarsat [11] and the National Environmental Agency of Georgia [12]; and the frequency of incidents (collisions, groundings, communication failures), reconstructed using data from DNV Cyber & FT Longitude [13]. The normative service life of electronic navigation equipment was assumed to be 10 years according to [13] and [11], which was an industry-standard figure for Total Cost of Ownership and investment model calculations by maritime operators. The choice of data ensured the representativeness of the scenario and its compliance with real-world operating conditions. The developed scenarios included both the separate modeling of AIS, ECDIS, GPS, GMDSS, IBS, and other systems, as well as their combined use. Each scenario also received a quantitative assessment of incident reduction, operational cost reduction, and improved navigational accuracy compared to the baseline model. For Georgia, additional factors included the heavy port traffic in Batumi and Poti, narrow channels, adverse weather, and low fleet digitalisation. This allowed the models to be adapted to the region's real conditions and objectively assess the effectiveness of the systems.

At the second stage, a quantitative assessment was conducted of the key operational, economic, and safety characteristics of navigation technologies. The selected parameters included prevalence, capital, and annual operating costs, Return on Investment, reduction in operational expenses, and the level of incident reduction. The parameters were selected based on industry standards as the most universal indicators of technological and investment efficiency in the maritime sector. Prevalence was considered a measure of technology maturity and a prerequisite for effective scalability. Financial costs (capital and operational) were used to calculate TCO and Lifetime Customer Value / Life Cycle Value (LCV), reflecting long-term benefit. ROI was applied as a universal indicator of investment efficiency. Cost reduction metrics were modelled as the result of integrating technologies into typical operational processes. The level of incident reduction was defined as an integral indicator of navigational safety, directly affecting insurance premiums and strategic operational reliability.

The third stage involved the assessment of user-friendliness (1-5 points) to quantitatively determine the ergonomics and intuitiveness of navigation systems using an adapted System Usability Scale (SUS), with scores ranging from 1 to 5 (1 indicating very poor usability requiring extensive training, and 5 indicating maximum intuitiveness and ease of use). The assessment was conducted on Transas Navi-Trainer Professional 5000 navigation simulators with 20 operators, including 12 final-year maritime students and 8 BSMA instructors with over 5 years of seafaring experience, who completed typical tasks (route planning, processing AIS signals). Results were processed using the arithmetic mean and statistically tested for consistency (Cronbach's $\alpha > 0.8$). For the regional scenario (Georgia), adjustments were made based on expert evaluations — lower scores for ECDIS (3.8→3.5) and IBS (4.0→3.8) were due to limited digital training, lack of adapted interfaces, and training infrastructure. The duration of certification courses, retraining frequency, and simulator usage costs were also taken into account. For Georgia, the model was adapted to account for increased rates (by 20-30%) and the need to hire external instructors.

In the fourth stage, an economic model was developed to quantitatively assess the investment feasibility of maritime navigation systems, including calculations of TCO, total savings, and LCV.

TCO was calculated as follows:

$$TCO = C_{init} + C_{train} + \sum_{t=1}^n (C_{oper,t} + C_{maint,t} + C_{upgrade,t}) - S_{res,n} [1]$$

where:

C_{init} — initial investment in hardware, software, installation, licenses,
 C_{train} — costs of training and retraining personnel to operate the system,
 $C_{oper,t}$ — operating costs in year t (operating period),
 $C_{maint,t}$ — Maintenance in year t ,
 $C_{upgrade,t}$ — grades and updates in year t ,
 $S_{res,n}$ — Residual value at the end of the life cycle (in year n (total life cycle of the technology or equipment, expressed in years)).

Regional adaptation used adjustment factors based on differences in resource costs (training, infrastructure). The factors ranged from +20% to +30%, reflecting the need for external contractors and the limitations of in-house training.

Total savings:

$$E_{econ} = \sum_{t=1}^n (C_{base,t} - C_{with_{tech,t}}) [2]$$

Where: E_{econ} — total economic effect (savings) for the entire period of operation,
 $C_{base,t}$ — Costs without the introduction of technology at time t , $C_{with_{tech,t}}$ — costs after the introduction of technology at the same time t

LCV:

$$LCV = \sum_{t=1}^n \frac{(C_{base,t} - C_{with_{tech,t}})}{(1+r)^t} - TCO [3]$$

Where: r – Discount rate.

Additionally, a profitability model for maritime navigation system insurance was developed, including forecasts of expected insurance discounts and annual premium savings, as well as ROI calculations. The discount was determined based on the percentage reduction in incidents, with a correlation coefficient reflecting insurance practices (0.8 for international fleets and 0.6 for Georgian fleets). Insurance savings were calculated as the product of the base premium rate (globally \$250,000 per year and in Georgia \$50,000 per year) and the expected discount. ROI was computed as the ratio of annual savings to the capital costs of a specific system. The model parameters were derived from simulated incident data, industry reports [11, 13], and consultations with insurance company representatives. The aim was to identify systems with the highest insurance return, especially when resources are limited, and fleet structures vary. An additional analysis of the operational characteristics of navigation technology was conducted by listing the advantages and limitations of each system globally, considering Georgia's specific maritime sector. The comparative results across all aspects provided the foundation for practical recommendations to optimize the use of navigation equipment in marine education and operations, taking into account the unique features of the Black Sea region.

To ensure the reliability of simulation scenarios and compliance with international standards [14-16], a specialized hardware and software complex was employed. Each component of the complex was chosen based on the tasks of specific modeling stages and the requirements for verifying the results. For comprehensive modeling of navigation operations under various conditions (port operations, open sea, and complex weather scenarios), the Transas Navi-Trainer Professional 5000 platform was used — an industry standard among navigation simulators, approved by [11] and [16]. It offered realistic integration of key ship systems, including AIS, ECDIS, GPS, radar, GMDSS, and IBS, enabling the simulation of complex operational scenarios. To evaluate electronic chart systems and route planning, certified solutions, Transas Navi-Sailor 4000 and Furuno FMD-3200, were utilized. Using both platforms allowed for a comparative analysis of navigation accuracy and user interface convenience. GPS signal simulation was performed with the Spirent GSS6700, a device widely used in maritime and aviation testing. It enabled simulation of real-world signal transmission conditions, including interference, spoofing, and temporary losses, which was essential for assessing vulnerabilities in positioning systems.

Radar navigation was simulated using Furuno FAR- 2117 and Sperry Marine VisionMaster FT, both compliant with [11] and commonly used in real- world navigation. This ensured the comparability of simulation results with actual operations. A GMDSS satellite communication simulation, including Search and Rescue (SAR) and SafetyNET functions, was conducted using Inmarsat- C terminals (International Maritime Satellite Communication system, Class C) and FleetBroadband. IBS

integration was modeled using the Kongsberg K- Bridge platform, which supported realistic visualization and data processing from multiple devices. This platform is widely used in training and certification, including standards like [16]. To replicate local Black Sea hydrometeorological conditions, weather stations and data from [12] were used, providing realistic simulations of wave height, precipitation, fog, and wind factors affecting navigation safety and system reliability. The usability and ergonomics of navigation equipment interfaces were evaluated using Oculus Rift virtual reality technology. VR modules offered immersive feedback and complemented traditional cognitive load assessments like SUS. Economic and operational analyses were performed with MATLAB (Matrix Laboratory)/Simulink and AnyLogic. MATLAB enabled complex mathematical modeling, while AnyLogic allowed agent- based simulation of navigation scenarios. Results were verified by comparing simulated data with international [11, 12] and regional [13] sources. Pearson correlation analysis assessed consistency at a significance level of $\alpha = 0.05$, with a correlation coefficient (r) above 0.85 indicating a high correlation. Additionally, simulated indicators were compared to industry standards and regional data [11-13, 16]. Simulations on the Transas platform confirmed the model's validity. Comparisons with market rates and a correlation coefficient of $r > 0.8$ provided a quantitative measure of the system's social applicability under limited resources.

Results and discussion.

The analysis of the economic and operational efficiency of navigation systems (AIS, ECDIS, GPS, radar systems, GMDSS, including Inmarsat, and IBS) revealed their impact on cost reduction, ROI, and shipping safety. The assessment covered both the global context and the regional conditions of Georgia's maritime industry. Table 1 compares marine systems, highlighting their influence on the economics of vessel operations.

Table 1. Economic efficiency of marine systems and technologies

System	Prevalence (%)	Implementation costs (USD)	Annual maintenance costs (USD)	ROI (%)	Cost reduction (%)
AIS	95	15000	2000	120	15
ECDIS	80	50000	5000	80	10
GPS	98	10000	1000	150	12
Radar systems	90	30000	3000	100	13
Inmarsat (GMDSS)	85	20000	4000	110	14
IBS	60	100000	10000	90	18

Note: The data did not reflect actual financial, insurance, or operational contracts, but were the result of simulation modeling approximating industry practice

Source: created by author based on author's modeling using hypothetical operational scenarios verified by DNV Cyber & FT Longitude [13], Inmarsat [11] industry reports

The highest return on investment (ROI) was achieved by the GPS (150%), mainly due to its high prevalence (98%), low implementation costs, and minimal operating expenses. The AIS system also demonstrated high efficiency (ROI – 120%) with moderate costs and a significant cost reduction effect (15%). ECDIS and Inmarsat (GMDSS), despite higher capital and annual costs, proved to be profitable solutions due to their broad applicability and functional importance. Specifically, Inmarsat showed a balanced cost-to-return ratio (ROI: 110%, cost reduction: 14%). The Integrated Bridge System (IBS) had the greatest potential for cost reduction (18%), but its high implementation cost (\$100,000) and moderate ROI (90%) limited large-scale deployment, especially on small and medium-sized vessels. Radar systems showed similar results, with stable efficiency indicators (ROI – 100%), but fell behind more compact and cost-effective solutions in ROI. When choosing navigation systems, it's essential to consider not only the absolute ROI but also the ratio of costs, the scale of application, and the long-term operational impact under specific conditions. The evaluation of the economic efficiency of navigation systems in Georgia's maritime sector reflected the financial performance of implementing key navigation systems across the country's maritime industry. Table 2 provides data on prevalence, capital and operational costs, ROI, and the extent of operational cost reductions.

The analysis of simulation modeling results showed that, within Georgia's maritime industry, the GPS, AIS, and Inmarsat (GMDSS) navigation systems exhibited the highest economic efficiency. The GPS had the highest return on investment (150%) with minimal capital and annual costs.

AIS, despite slightly higher maintenance expenses, delivered the highest ROI (125%) and the greatest cost-reduction effect (18%) among all systems, making it

especially advantageous for widespread use. The Inmarsat (GMDSS) system demonstrated a balanced efficiency-to-cost ratio, with an ROI of 110% and a 14% cost reduction, highlighting its importance in providing reliable communication under the challenging hydro-meteorological conditions of the Black Sea.

Table 2. Assessment of the economic efficiency of marine technologies in Georgia

System	Prevalence (%)	Implementation costs (USD)	Annual maintenance costs (USD)	ROI (%)	Cost reduction (%)
AIS	90	15000	2000	125	18
ECDIS	70	50000	5000	80	10
GPS	95	10000	1000	150	12
Radar systems	85	30000	3000	100	13
Inmarsat (GMDSS)	80	20000	4000	110	14
IBS	30	100000	10000	85	18

Note: The data did not reflect actual financial, insurance, or operational contracts, but were the result of simulation modeling approximating industry practice

Source: created by author based on author's modeling using hypothetical operational scenarios verified by DNV Cyber & FT Longitude [13], Inmarsat [11], National Environmental Agency of Georgia [12] industry report data.

Conversely, IBS and ECDIS showed lower profitability (ROI of 85% and 80%, respectively) and were coupled with high implementation costs. This was particularly true for IBS, which, despite its significant cost reduction potential, had limited adoption (30%)—likely due to technological and institutional barriers, including insufficient crew training and limited digital infrastructure in ports.

The results of the evaluation of the impact of navigation system implementation on maritime transport safety provided a quantitative measure of how navigation systems influence accident reduction in two scenarios: the global context and Georgia specifically (Table 3).

The research results showed significant differences in the effectiveness of navigation systems depending on the scenario (global or regional — Georgia). Within the international fleet, most systems exhibited a moderate decrease in incidents, ranging from 5% to 8%, highlighting their fundamental role in ensuring navigational safety. The most effective system in the international context was the IBS (8% reduction), attributed to its ability to process data centrally and reduce human error. AIS and Inmarsat (GMDSS) also proved effective (7.6% and 7%, respectively) due to their monitoring and communication functions. However, in the Georgian context, the effectiveness of specific systems increased markedly. The most notable improvement

was demonstrated by AIS, resulting in a 20% reduction in incidents, due to its critical importance when operating in areas with high traffic density, narrow routes, and limited visibility.

Table 3. Impact of navigation systems on reducing incidents in maritime transport

System	Decrease in incidents (%)	Reduction of incidents in Georgia (%)
AIS	7.6	20
ECDIS	5	5
GPS	5	5
Radar systems	6	6
Inmarsat (GMDSS)	7	15
IBS	8	8

Note: The data did not reflect actual financial, insurance, or operational contracts, but were the result of simulation modeling approximating industry practice

Source: created by author based on author's modeling using hypothetical operational scenarios verified by DNV Cyber & FT Longitude [13], Inmarsat [11], National Environmental Agency of Georgia [12] industry report data.

Inmarsat also contributed significantly to safety, with a 15% reduction, thanks to its reliable communication in the challenging weather conditions of the Black Sea. Other systems (GPS, ECDIS, and radar complexes) maintained steady efficiency in both global and regional scenarios (5-6%), reflecting their role as essential but not regionally adaptive solutions. In Georgia, IBS maintained its global reduction level (8%), although its impact could have been considerably greater if broader integration across the fleet had been implemented.

Table 4. Social aspects of navigation systems' operation in the maritime industry

System	Usability rating (1-5)	Tuition fees (USD)
AIS	4.6	1000
ECDIS	3.8	5000
GPS	4.8	500
Radar systems	3.2	2000
Inmarsat (GMDSS)	4.4	2000
IBS	4.0	10000

Note: The data did not reflect actual financial, insurance, or operational contracts, but were the result of simulation modelling approximating industry practice

Source: created by author based on author's modelling using hypothetical operational scenarios verified from DNV Cyber & FT Longitude [13], Inmarsat [11] industry reports

The results indicated that GPS and AIS were the most user-friendly systems, earning high scores (4.8 and 4.6, respectively) due to their intuitive interfaces and low learning curve. The minimal training costs for GPS (\$500) and AIS (\$ 1,000) made these systems accessible to crews with different levels of experience. Inmarsat (GMDSS) also showed high usability (4.4), with moderate training expenses (\$ 2,000), highlighting its effectiveness in facilitating communication. Conversely, ECDIS and radar systems received lower usability ratings (3.8 and 3.2), likely due to their complexity and the need for extensive training. Although IBS had an average usability score (4.0), it required a substantial training investment (\$10000), which limited its adoption, especially on vessels with limited resources. This demonstrates that systems with high intuitiveness and low training costs (GPS, AIS) are the most favorable for widespread adoption.

To evaluate the social relevance of navigation technologies in Georgia's maritime industry, an analysis of usability and crew training costs was also conducted. Table 5 presents the results of the analysis of key social parameters involved in the operation of navigation systems in Georgia's maritime sector.

Table 5. Usability and training cost indicators for marine technologies in Georgia

System	Usability Rating (1-5)	Tuition fees (USD)
AIS	4.6	1500
ECDIS	3.5	6000
GPS	4.8	500
Radar systems	3.2	2500
Inmarsat (GMDSS)	4.4	2500
IBS	3.8	12000

Note: The data did not reflect actual financial, insurance, or operational contracts, but were the result of simulation modeling approximating industry practice

Source: created by the author based on the author's modeling using hypothetical operational scenarios verified by DNV Cyber & FT Longitude [13], Inmarsat [11], National Environmental Agency of Georgia [12] industry report data.

According to the modeling and expert assessment, GPS (4.8) and AIS (4.6) were recognized as the most user-friendly systems in operation. These systems featured intuitive interfaces, a high degree of automation, and required minimal personnel training time. The low training costs made these systems particularly attractive for widespread adoption within the regional fleet. Inmarsat (GMDSS) also showed a high level of user accessibility (score 4.4) with average training costs, reflecting the standardized approach to training under the internationally adopted GMDSS framework. Meanwhile, ECDIS and IBS received lower usability ratings (3.5 and 3.8, respectively), indicating interface complexity, high integration requirements with other

systems, and the need for specialized training. This was especially evident with IBS, where training costs reached \$12,000—given the low level of fleet digitalization in Georgia—thereby limiting its widespread adoption. Radar systems proved to be the least user-friendly (score 3.2), most likely due to the need for manual signal interpretation and limited automation, especially on outdated platforms.

To provide a detailed assessment of the applicability of navigation systems, a comparative analysis of their operational characteristics was conducted. Table 6 presents the primary advantages and limitations of each technology, considering the impact on safety, costs, return on investment, and crew training requirements.

Table 6. Functional and operational characteristics of marine navigation systems

System	Advantage	Disadvantages
AIS	Reduced incidents by 7.6% through real-time monitoring. High usability rating (4.6) due to the simple interface. Low implementation and maintenance costs. ROI 120% due to reduced insurance premiums. Support for dense traffic in ports	Vulnerability to cyberattacks (GPS spoofing, data interception). Limited effectiveness in stand-alone systems without integration with IBS. Training costs (1 thousand USD) due to the need for crew certification
ECDIS	Reducing costs by 10% through precise route planning. 5% reduction in incidents under challenging waters. Ensuring compliance with IMO navigation standards. Support for digital maps updated in real time	Complex software reduces the usability rating. High costs for implementation and maintenance. Training costs due to human factors and certification. Operator errors increase risks.
GPS	High positioning accuracy (up to 1 m), high usability rating (4.8) due to simplicity. Minimal costs for training and implementation. Route optimization reduces fuel costs by 12%	Vulnerable to jamming and spoofing, especially in conflict zones. Limited reduction in incidents (5%). Dependence on satellite infrastructure
Radar systems	Reduction of incidents by 6% in conditions of poor visibility (fog, night). Average implementation and maintenance costs. Reliable in detecting objects up to 24 miles away	Low usability rating (3.2) due to calibration required. Training costs (2 thousand USD) for working with the interface. Limited effectiveness in dense traffic without AIS
Inmarsat (GMDSS)	Reducing incidents by 7% due to reliable satellite communications. High convenience rating. IoT (Internet of Things) for data transfer.	High maintenance costs (4000 USD/year) and implementation costs (20000 USD). Training costs for setting up equipment.

	Efficiency in storm conditions	Dependence on a satellite network
IBS	18% cost reduction achieved through the integration of all systems. Reduction in incidents by 8%. Support for autonomous navigation, reducing crew workload	High costs for implementation (100,000 USD) and maintenance (10,000 USD/year). Training costs are due to complexity. Low prevalence (60%) due to cost. Difficulty of integration with legacy vessels

Source: created by the author based on Y. Han & L. Chu [17], M.-H. Hsieh et al. [18], Inmarsat [11], DNV Cyber & FT Longitude [13], S. Liu et al. [19], N. Veltsin et al. [20], R. G. Wright [21], T. Yuzui & F. Kaneko [22], J. Zhang et al. [23], L. Yang et al. [24].

AIS was the most cost-effective option, offering a high ROI and strong performance in dense traffic; however, it was vulnerable to cyberattacks and less effective without integration with IBS. ECDIS ensured compliance with IMO standards and enabled accurate route planning, but its complex software and high implementation costs required extensive training. GPS was notable for its high accuracy and ease of use, reducing fuel consumption, though it was susceptible to interference. Radar systems were reliable in poor visibility conditions but were difficult to operate and less effective in crowded traffic. Inmarsat (GMDSS) provided dependable communication and IoT support, albeit at high installation and maintenance costs. IBS led in cost reduction and incident prevention, supporting autonomy, but its high cost and integration challenges limited its use on older vessels. The best system depended on the shipowner's priorities. For cost-efficiency and simplicity, AIS and GPS were preferred; for challenging environments, radars and Inmarsat were used; and for maximum efficiency and autonomy, IBS was chosen despite its expense.

System integration could have minimized limitations and enhanced overall safety and performance. The study showed that AIS and IBS contributed to maritime safety by integrating navigational data and advanced information processing. Y. Zhou et al. [25] confirmed AIS's effectiveness in reducing incidents through the development and successful testing of a collision avoidance algorithm based on AIS data and an improved Dynamic Window Approach (DWA) in high-traffic scenarios. The research also explored the integration of navigation systems and autonomous navigation support, highlighting IBS's potential in complex navigational environments. T.-E. Hung & C.-C. Chang [26] conducted an empirical study using a navigational simulator to evaluate navigators' mental workload across different systems. Using NASA Task Load Index (NASA-TLX) methods and response-time metrics, they found that ECDIS operators experienced significantly higher cognitive load than users of other systems. The authors attributed this to the system's interface complexity, the need to interpret

cartographic data, and higher training requirements. Our current findings align with these, as ECDIS received a low usability rating (3.5) and incurred high training and implementation costs, limiting its practical use despite its compliance with standards and potential for route optimization. M. Ammar and I. A. Khan [27] reviewed over 70 incidents from the past decade, finding that roughly 60% of cyberattacks stemmed from vulnerabilities in navigational channels—such as AIS, GPS, and Inmarsat spoofing and data interception. Besides technical issues such as the absence of encryption, organizational weaknesses, including a lack of standards, insufficient crew training, and poor monitoring, were also noted. These insights aligned with our current results, which identified AIS, GPS, and Inmarsat as the most vulnerable systems despite their widespread use. This vulnerability compromised system reliability, particularly in high-risk zones such as the Black Sea, underscoring the need for protective measures such as encryption, authentication, and backup channels. Cyber threats must also be considered when evaluating navigational solutions. Data from modeling showed that radar systems, despite a moderate usability score (3.2) and the need for crew training, consistently reduced incidents by 6% under limited visibility. This reaffirmed the importance of radar as a critical part of safety systems, especially in regions with weak satellite signals and unstable communications. These findings agree with J. Wang et al. [28], who developed a Bayesian model for assessing navigational risk, considering radar characteristics, weather, traffic density, and alternative navigation tools. Their simulation demonstrated that radar maintained high detection accuracy and stability even without GPS signals. The model also detailed threshold conditions under which radar becomes crucial for timely threat detection, especially at night and in low visibility. An analysis of the advantages and limitations of navigation systems for Georgia, taking into account regional specifics of the Black Sea, port infrastructure (Batumi, Poti), fleet digitalization levels, socio-economic factors, and cyber risks, was also conducted (see Table 7).

The AIS and GPS systems stood out for their affordability, ease of operation, and low personnel qualification requirements, which were particularly important for Georgian ports with heavy traffic and limited resources. However, the vulnerability to cyber threats and reliance on satellite channels required additional cybersecurity measures and backup support. The ECDIS navigation systems and Inmarsat (GMDSS) communication platform were strategically important for improving safety; however, their implementation was limited by high costs and the need for developed infrastructure, especially on small- and medium-tonnage vessels. Radar systems were crucial in poor visibility, which was typical for the Black Sea. Still, these systems required integration with AIS and highly qualified operators, thereby reducing their effectiveness when used in isolation. IBS systems remained uncommon in Georgia due to high costs, complexity of adaptation, and the lack of digital platforms for integration. In the short- and medium-term perspectives, the most significant potential for Georgia was demonstrated by AIS, GPS, and, to a lesser extent, by Inmarsat (GMDSS). For the

broadier implementation of the remaining systems, infrastructure modernization, state support, education development, and enhanced cybersecurity were necessary.

Table 7. Advantages and disadvantages of marine navigation systems in the context of Georgia

System	Advantages	Disadvantages
AIS	Support for real-time monitoring is essential for the dense traffic in Georgian ports. Simplicity of interface, minimizing the need for training	Vulnerability to cyberattacks, especially in the context of geopolitical risks in the Black Sea. Requires integration with other systems to be effective. Limited port infrastructure
ECDIS	Precise route planning in the tricky waters of the Black Sea. Compliance with IMO standards for international ships	Complex software requires training. High implementation costs. Limited hydrographic infrastructure in Georgia
GPS	High precision and ease of use. Suitable for fuel economy	Vulnerability to interference in conflict zones. Dependence on a satellite network
Radar systems	Reliability in poor visibility conditions, which are common in the Black Sea	The complexity of calibration requires training. Limited effectiveness in dense traffic without AIS
Inmarsat (GMDSS)	Reliable satellite communications in stormy conditions of the Black Sea. SAR (Search and Rescue) operations and SafetyNET II for warnings	High costs for implementation and maintenance. Vulnerability to cyberattacks. Limited port infrastructure
IBS	Integration of systems for autonomous navigation is promising for large vessels.	High costs, difficulty of integration with obsolete vessels. Low prevalence in Georgia

Source: created by the author based on National Environmental Agency of Georgia [12], Inmarsat [11], DNV Cyber & FT Longitude [13]

To assess the feasibility of investing in various maritime navigation technologies, a global analysis of TCO and LCV was conducted. Table 8 presents the average assessment of TCO, cumulative savings, and LCV of maritime navigation technologies, considering typical operational intensity and international implementation conditions (Formulas 1-3).

Table 8. Economic evaluation of TCO and LCV of marine navigation technologies

System	TCO (USD)	Total Savings (USD)	LCV (USD)
AIS	25000	55000	30000
ECDIS	45000	50000	5000
GPS	80000	50000	-30000
Radar systems	80000	45000	-35000
Inmarsat (GMDSS)	150000	60000	-90000
IBS	300000	200000	-100000

Note: The data did not reflect actual financial, insurance, or operational contracts, but were the result of simulation modeling approximating industry practice

Source: created by the author based on the author's modeling using hypothetical operational scenarios verified from DNV Cyber & FT Longitude [13], Inmarsat [11] industry report data.

The results of the economic efficiency analysis showed that AIS systems achieved the best TCO-to-cumulative-savings ratio, resulting in a positive LCV value. Similarly, ECDIS demonstrated relatively low costs and moderate savings, which resulted in a positive, albeit smaller, LCV value (USD 5,000). GPS, radar systems, Inmarsat (GMDSS), and IBS were characterized by high total cost of ownership, exceeding cumulative savings and resulting in negative LCV values (USD -30,000, -35,000, -90,000, and -100,000, respectively). This indicated that, under current operating conditions, these technologies were not economically viable over the analyzed period. From an economic standpoint, for long-term maritime navigation, preference should have been given to AIS and ECDIS systems. In contrast, the use of other technologies required additional justification, taking into account both strategic and operational factors.

The study by L. Zhao et al. [29] examined the impact of integrating AIS, GPS, and Inmarsat systems on shipping economics along the Singapore-Rotterdam corridor. The authors concluded that AIS, due to its technological maturity, high compatibility with other systems, and moderate operating costs, yielded steady savings at a large scale. These findings align with the present study, in which AIS demonstrated the most stable TCO-to-savings ratio.

Technologies with a high degree of integration and digitalization, such as IBS, proved economically unviable without adequate infrastructural and organizational support. This was confirmed by the findings of D. Menges et al. [30], who, using a digital twin of an autonomous vessel, showed that complex navigation architectures incurred high costs for implementation, training, and technical maintenance. Meanwhile, the positive economic effects only became apparent with widespread standardization and a high level of autonomy. This explained the negative LCV values for IBS and Inmarsat (USD -100,000 and -90,000), as reflected in the current modeling

results. Comparing with literature sources, the assessment's reliability was confirmed, highlighting the importance of adapting navigation systems to specific economic and infrastructural conditions, especially when choosing between mature technologies and innovative solutions.

Table 9 presents an adapted economic assessment of maritime navigation systems, considering the specific characteristics of the Georgian naval sector—particularly the limited tonnage of the national fleet, relatively low capital and operating costs, and the unique navigation conditions in the Black Sea basin and the ports of Batumi and Poti.

Table 9. Economic analysis of the costs and benefits of marine navigation systems for Georgia

System	TCO (USD)	Total Savings (USD)	LCV (USD)
AIS	26500	190000	163500
ECDIS	81000	75000	-6000
GPS	15500	85000	69500
Radar systems	47500	95000	47500
Inmarsat (GMDSS)	42500	145000	102500
IBS	162000	130000	-32000

Note: The data did not reflect actual financial, insurance, or operational contracts, but were the result of simulation modeling approximating industry practice

Source: created by author based on author's modeling using hypothetical operational scenarios verified by DNV Cyber & FT Longitude [13], Inmarsat [11], National Environmental Agency of Georgia [12] industry report data

The research results in the context of Georgia demonstrated differences relative to global indicators, which were attributed to adapting calculations to the conditions of the Georgian maritime sector — a smaller fleet scale, lower implementation costs, and a more pronounced effect of digitalization within the limited Black Sea area. The AIS system demonstrated the highest economic efficiency, with an LCV of USD 163,500, attributable to its widespread use, low cost, and significant contribution to improving safety in the ports of Batumi and Poti. Significant LCV values were also recorded for Inmarsat (GMDSS) (USD 102,500) and GPS (USD 69,500), highlighting the importance of accurate navigation and stable communication under the region's complex hydrometeorological conditions

Table 10. Economic efficiency of navigation systems, taking into account insurance savings

System	Decrease in incidents (%)	Estimated insurance discount (%)	Premium savings (USD/year)	ROI on insurance
AIS	7.6	9	22500	150
ECDIS	5	6	15000	150
GPS	5	5	12500	25
Radar systems	6	6	15000	50
Inmarsat (GMDSS)	7	8	20000	100
IBS	8	12	30000	30

Note: The data did not reflect actual financial, insurance, or operational contracts, but were the result of simulation modeling approximating industry practice

Source: created by author based on author's modeling using hypothetical operational scenarios verified by DNV Cyber & FT Longitude [13], Inmarsat [11] industry reports

Radar systems provided a positive LCV due to their reliability in low-visibility conditions and acceptable operating costs. ECDIS (USD -6,000) and especially IBS (USD -32,000) showed negative life cycle values due to high implementation and training costs, as well as the lack of a developed infrastructure for comprehensive digital integration. Additionally, Table 10 demonstrated the economic efficiency of navigation technologies through reduced insurance premiums.

The IBS and AIS systems demonstrated excellent efficiency in insurance-related matters. Despite high capital expenditure, IBS provided the maximum insurance discount (12%) and savings of up to USD 30,000 per year, corresponding to a 30% ROI. AIS, due to its high effectiveness in preventing navigational incidents, enabled savings of USD 22,500 with a 150% ROI — the highest among all systems. Inmarsat (GMDSS) and ECDIS also provided significant insurance-related benefits (USD 20,000 and USD 15,000 per year, respectively), reflecting the role in enhancing communication and navigation safety in adverse conditions. The ROI for these technologies ranged from 100% to 150%. GPS and radar systems yielded moderate insurance returns (USD 12,500-15,000 per year) with relatively low ROI, especially for GPS (25%), which was attributed to the perception of these systems as basic equipment with limited influence on insurance coefficients. Additionally, Table 11 presents the results of a comparative analysis of insurance ROI for navigation systems in Georgia's maritime sector.

Table 11. Potential insurance benefits from the introduction of marine navigation technologies in Georgia

System	Decrease in incidents (%)	Estimated insurance discount (%)	Premium savings (USD/year)	ROI on insurance
AIS	20	12	6000	40
ECDIS	5	3	1500	3
GPS	5	3	1500	15
Radar systems	6	3.6	1800	6
Inmarsat (GMDSS)	15	9	4500	22.5
IBS	8	4.8	2400	2.4

Note: The data did not reflect actual financial, insurance, or operational contracts, but were the result of simulation modeling approximating industry practice

Source: created by author based on author's modeling using hypothetical operational scenarios verified by DNV Cyber & FT Longitude [13], Inmarsat [11], National Environmental Agency of Georgia [12] industry report data

The results indicated that the AIS system provided the most significant insurance benefit in the Georgian context, offering savings of 6,000 USD per year and a 40% ROI, due to a considerable reduction in incidents and the technology's availability. Inmarsat (GMDSS) also showed high potential (savings of 4,500 USD, ROI of 22.5%), reflecting its value in ensuring stable communication and safety. Other systems, such as ECDIS, GPS, radar technologies, and IBS, were characterized by significantly lower ROI (2.4-15%), which limited their attractiveness in Georgia.

The economic efficiency analysis of navigation systems considering insurance savings was supported by existing research on risk management and improving maritime transport safety. T. Rabus [31], in the work, focused on a comprehensive approach to managing external risks in the aviation and marine sectors, emphasising that the integration of modern navigation technologies could significantly reduce the likelihood of emergencies and, as a result, reduce insurance costs. This correlated with the modeling data, which showed that IBS and AIS systems demonstrated the highest insurance efficiency and ROI despite significant capital investment.

Additionally, W. Pan et al. [32] demonstrated that the introduction of intelligent navigation support algorithms, capable of adapting to temporary local restrictions and complex navigation conditions, increased navigation accuracy and reliability. This aligned with the current study on substantial insurance savings from using AIS and IBS, where improved navigation data processing methods and collision avoidance algorithms were applied. This was especially relevant for regional markets with diverse economic and infrastructure conditions, such as the Georgian maritime sector, where the efficiency of navigation system implementation varied depending on operational specifics and fleet technical readiness.

The results of this study informed practice-oriented recommendations for shipping companies, port operators, logisticians, and regulators, taking into account both global trends and the specific nature of Georgia's maritime sector. The analysis of economic and operational indicators confirmed the high efficiency of AIS and GPS systems, characterized by low capital and operating costs and by significantly reducing navigation risks and insurance premiums. It was proposed to ensure the widespread installation of AIS and GPS systems on ships, including government co-financing measures for small-tonnage fleets, and to expand the use of AIS in port traffic monitoring systems. For medium- and large-tonnage vessels, a phased transition to IBS was advisable, despite high implementation and training costs, as it demonstrated a synergistic effect in reducing navigation risks and increasing crews' situational awareness. It was recommended to include IBS in fleet modernization programs, to introduce it into port VTS systems, and to develop educational platforms in cooperation with international maritime organizations.

The use of ECDIS and GPS systems contributed to the efficiency of maritime logistics by enabling accurate route planning, reducing anchorage time, minimizing supply disruptions, and integrating with logistics IT systems. It was necessary to intensify the use of ECDIS in the fleet and ports, as well as to modernize the hydrographic base and digital infrastructure. Navigation technologies, primarily AIS, Inmarsat, and IBS, were recognized by insurers as tools for risk reduction, which provided insurance discounts of 5-12%. It was recommended to certify these systems to IMO standards and to use verified data on incident reduction when negotiating with insurance companies.

Given the specifics of the Georgian maritime sector (small fleet, complex weather conditions, limited resources), it was advisable to subsidise the installation of AIS and ECDIS on small-tonnage vessels, introduce IBS into port logistics and dispatching, implement crew training programmes in partnership with the International Maritime Organization (IMO) and the European Maritime Safety Agency (EMSA), as well as to develop cyber resilience of port and vessel infrastructure. The growth of digitalization increased the vulnerability of navigation solutions to cyber threats (signal interception, spoofing, system interference), prompting the implementation of comprehensive protection measures (encryption, anomaly monitoring) and the development of national cybersecurity protocols in the maritime sector. The proposed measures were based on a comparison of efficiency indicators, risks, and costs. They could be applied both to the strategic planning of shipping companies and to state policy in the fields of maritime safety and the digitalization of transport infrastructure.

The study's results confirmed the high economic and operational efficiency of AIS and GPS systems, as well as the expediency of phased IBS implementation and the expansion of digitalization in Georgia's maritime sector. These findings were supported by academic research, which reinforced the practical relevance of the proposed recommendations. The study by X. Liu and K. F. Yuen [33] demonstrated the wide-

ranging opportunities for applying AI and digital technologies in ports, which aligns with this study's recommendation to develop port monitoring systems based on AIS and IBS. The authors emphasized the need to enhance the cyber resilience of digital infrastructure. This need was particularly relevant to Georgia's maritime sector, given the increasing digitalization and associated cyber risks. The introduction of comprehensive protection measures, including data encryption and anomaly detection, could reduce the vulnerability of navigation systems, which aligns with the study's findings on the need for national cybersecurity protocols.

The work of T. Nakashima et al. [34] focused on managing systemic risks in autonomous maritime navigation using structured System-Theoretic Process Analysis (STPA) and the Operational Design Domain (ODD), thereby reinforcing the importance of integrating complex systems, such as IBS, to enhance crew situational awareness and reduce the likelihood of navigation incidents. These conclusions were consistent with the study's current recommendations on including IBS in fleet modernization programs, especially for medium- and large-tonnage vessels, where improved safety and insurance savings offset implementation costs.

The real-time anomaly detection methodology for ship behavior presented by Y. Qi et al. [35] confirmed the practical value of modern monitoring systems in reducing the number of incidents and insurance premiums. The use of deep learning algorithms, a combination of Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM), allowed timely detection of deviations and potential threats, supporting prompt decision-making by crews and port services, thus confirming the relevance and effectiveness of the monitoring systems identified in this study, aimed at reducing navigation risks and insurance premiums. The ability to detect deviations and threats was crucial for the Georgian fleet, considering its climatic conditions and limited resources.

The study by H. S. Berg et al. [36] explored the application of digital twins and advanced control methods for autonomous surface vessels, which supported this research in highlighting the potential for integrating advanced navigation technologies into the maritime industry. The use of digital twins enabled the modeling and optimization of navigation processes, improving route planning and reducing the risk of accidents. This also supported the current study's recommendations on implementing IBS and developing educational platforms for crews in cooperation with international maritime organizations.

Therefore, the synthesis of research findings with academic publications confirmed the rationale for the widespread installation of AIS and GPS systems on vessels, expanding the use of integrated bridge systems (IBS), modernizing port systems and digital infrastructure, and strengthening cybersecurity. These steps not only enhanced navigation safety and reduced risks but also ensured significant savings by lowering insurance premiums and optimizing operational processes. Particular

attention should be paid to integrating advanced scientific achievements into Georgia's national maritime safety and transport digitalization strategy.

Conclusions.

The conducted study showed that AIS and Inmarsat (GMDSS) systems were the most effective in terms of overall benefit. In Georgia's context, automatic identification reduced navigation incidents by 20% and yielded annual insurance savings of \$ 6,000, with a return on investment (ROI) of 40%. In comparison, satellite communication enabled a 15% reduction in accidents. Both solutions demonstrated the highest life-cycle value (LCV) — \$163,500 and \$102,500, respectively. Significant profitability indicators were also identified for the GPS, whose simplicity, high accuracy, and low operating costs ensured an ROI of 150% and an LCV of 69,500 USD. However, in the Black Sea context, its effectiveness was limited by the vulnerability to signal interference and the lack of local signal redundancy.

The study results confirmed the expediency of implementing ECDIS and radar systems when proper infrastructure was available. Despite moderate ROI (80% and 100% respectively), these technologies ensured reliable navigation under challenging conditions and yielded a positive LCV (47,500 USD for radar). Nevertheless, the widespread use was constrained by high training costs (up to 6,000 USD) and complex interfaces. IBS systems showed potential to reduce costs (up to 18%) and incidents (8%). However, an economic analysis revealed a negative levelized cost of ownership (LCV) of -32,000 USD due to high costs and institutional barriers to integration into Georgia's fleet. The choice of navigation technology should be based on a balance between price, safety, and insurance benefits. Shortly, AIS, GPS, and Inmarsat were priorities for Georgia, while the implementation of IBS and ECDIS required state support and infrastructure modernization.

The study's limitations were related to the use of simulation modeling and hypothetical scenarios, which required further validation under real conditions. Also noted were the subjectivity of expert assessments, simplified insurance premium models, the absence of discounting in TCO and LCV calculations, limited incident data in Georgia, and simplified scenarios excluding extreme conditions. A promising direction for future research was the development of large-scale digitalization scenarios in Black Sea ports, the analysis of cyber threat risks, and the assessment of the effects of integrating AI solutions into the navigation architecture.

References.

- [1] Santos, N. P., Moura, R., Antunes, T. L., & Lobo, V. (2024, April 15–18). *Uncrewed vehicles: A promising solution to addressing sea pollution*. In 2024, OCEANS - Singapore (OCEANS 2024). IEEE. <https://ieeexplore.ieee.org/document/10682272>

- [2] Rao, X., Yuan, C., Guo, Z., Xu, Y., & Sheng, C. (2025). Methanol as an alternative fuel for marine engines: A comprehensive review of current state, opportunities, and challenges. *Renewable Energy*, 252, Article 123562. <https://www.sciencedirect.com/science/article/abs/pii/S0960148125012248?via%3Dihub>
- [3] Ma, J., Wang, L., Xu, L., Zhao, J., & Lin, R. (2025). Intelligent construction and analysis of a complex network for determining risk-influencing factors in ship self-sinking accidents. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, 11(3), Article 04025025. <https://ascelibrary.org/doi/10.1061/AJRUA6.RUENG-1559>
- [4] Li, M., Zhao, X., Jiao, Y., Liu, C., Chu, X., & Mou, J. (2025). Research on the risk of submarine cable damage from anchored ships based on probability analysis. *Reliability Engineering and System Safety*, 261, Article 111114. <https://www.sciencedirect.com/science/article/abs/pii/S0951832025003151?via%3Dihub>
- [5] Zhang, M., Zhang, X., Fu, S., Dai, L., & Yu, Q. (2023). Recent developments and knowledge in intelligent and safe marine navigation. *Journal of Marine Science and Engineering*, 11(12), 2303. https://www.mdpi.com/2077-1312/11/12/2303?utm_source=
- [6] Dagdilelis, D., Grigoriadis, P., & Galeazzi, R. (2025). Multimodal and Multiview Deep Fusion for Autonomous Marine Navigation *arXiv*. https://arxiv.org/abs/2505.01615?utm_source=
- [7] Menges, D., & Rasheed, A. (2024). Digital Twin for Autonomous Surface Vessels: Enabler for Safe Maritime Navigation. *arXiv*. https://arxiv.org/abs/2411.03465?utm_source=
- [8] Ma, F., Wang, X., Chen, C., Xu, X., & Yan, X. (2025). *Navigation-GPT: A robust and adaptive framework utilizing large language models for navigation applications* [Preprint]. *arXiv*. https://arxiv.org/abs/2502.16402?utm_source=
- [9] Mamuladze, R., & Mamuladze, G. (2025). The role of the maritime transport logistics system of Georgia in ensuring the stability of the global supply chain. *B Intelligent Transport Systems: Ecology, Safety, Quality, Comfort (ITSESQC 2024)* (c. 363–371). https://link.springer.com/chapter/10.1007/978-3-031-87376-8_32?utm_source=
- [10] Gechbaia, B., & Tsilosani, A. (2023). Prospects for intermodal and container transportation for Georgia's integration into the global transport market. *Access to Science, Business, Innovation in Digital Economy, ACCESS Press*, 4(1), 85–101. https://journal.access-bg.org/issue-4-1-2023/prospects_for_intermodal_and_container_transportation_for_georgias_integration?utm_source=
- [11] Inmarsat. (2024). *The future of maritime safety 2024* [PDF]. <https://www.inmarsat.com/content/dam/inmarsat/corporate/documents/maritime/insig>

https://inmarsat-maritime-future-maritime-safety-report-2024.pdf?utm_source=

[12] National Environmental Agency of Georgia. (2024, March). *National Report – Georgia (BASWG17)*. 17th Meeting of the Black and Azov Seas Working Group (BASWG), Batumi, Georgia. International Hydrographic Organization. https://iho.int/uploads/user/Inter-Regional%20Coordination/RHC/MBSHC/BASWG/BASWG17/BASWG17_2024_03C.2A_EN_GEORGIA_National%20Report.pdf?utm_source=

[13] DNV Cyber & FT Longitude. (2024). *Maritime Cyber Priority 2024/25: Managing cyber risk to enable innovation*. DNV. https://chiefengineerlog.com/wp-content/uploads/2024/12/MARITIME-CYBER-PRIORITY-2024-2025.pdf?utm_source=

[14] International Telecommunication Union. (2014). Technical characteristics for an automatic identification system using time division multiple access in the VHF maritime mobile frequency band (*Recommendation ITU-R M.1371-5*). <https://www.itu.int/rec/R-REC-M.1371/en>

[15] International Electrotechnical Commission. (2015). *Maritime navigation and radiocommunication equipment and systems — Electronic chart display and information system (ECDIS) — Operational and performance requirements, methods of testing and required test results* (IEC Standard No. 61174:2015). <https://webstore.iec.ch/en/publication/23128>

[16] Det Norske Veritas (DNV). (n.d.). *Rules and Standards for Maritime Simulators and Equipment*. <https://rules.dnv.com/servicedocuments/dnvpml/>

[17] Han, Y., & Chu, L. (2025). A systematic review and bibliometric analysis for maritime emergency management. *Journal of Sea Research*, 205, Article 102585. https://www.sciencedirect.com/science/article/pii/S1385110125000243?pes=vor&utm_source=scopus&getft_integrator=scopus

[18] Hsieh, M.-H., Xia, Z., & Chen, C.-H. (2024). Human-centred design and evaluation to enhance safety of maritime systems: A systematic review. *Ocean Engineering*, 307, Article 118200. <https://www.sciencedirect.com/science/article/abs/pii/S0029801824015385?via%3DiHub>

[19] Liu, S., Zhu, L., Huang, F., Hassan, A., Wang, D., & He, Y. (2024). A survey on air-to-sea integrated maritime Internet of Things: Enabling technologies, applications, and future challenges. *Journal of Marine Science and Engineering*, 12(1), Article 11. <https://www.mdpi.com/2077-1312/12/1/11>

[20] Veltsin, N., Chountalas, P. T., Koutsouki, E., Karvounidi, M. D., & Fouteris, A. E. (2025). Modeling Human Critical Success Factors for Maritime Safety: A DEMATEL Approach. *Safety Science*, 189, Article 106886. https://www.sciencedirect.com/science/article/pii/S0925753525001110?pes=vor&utm_source=scopus&getft_integrator=scopus

[21] Wright, R. G. (2024). *Ship sensors: Conventional, unmanned, and autonomous*. CRC Press.

<https://www.taylorfrancis.com/books/mono/10.1201/9781003377900/ship-sensors-glenn-wright>

[22] Yuzui, T., & Kaneko, F. (2025). Toward a hybrid approach for the risk analysis of maritime autonomous surface ships: A systematic review. *Journal of Marine Science and Technology*, 30(1), 153–176.

https://link.springer.com/article/10.1007/s00773-024-01040-0?utm_source=getftr&utm_medium=getftr&utm_campaign=getftr_pilot&getft_integrator=scopus

[23] Zhang, J., Yang, F., Li, J., Sun, Z., Zhang, R., & Zhao, L. (2025). Integrity monitoring for real-time precise point positioning in a maritime precise operating environment. *Measurement: Journal of the International Measurement Confederation*, 253, Article 117574.

<https://www.sciencedirect.com/science/article/abs/pii/S0263224125009339?via%3Diuhub>

[24] Yang, L., Liu, J., Zhou, Q., Liu, Z., Chen, Y., Wang, Y., & Liu, Y. (2025). Enabling autonomous navigation: Adaptive multi-source risk quantification in maritime transportation. *Reliability Engineering and System Safety*, 261, Article 111118.

https://www.sciencedirect.com/science/article/pii/S0951832025003199?pes=vor&utm_source=scopus&getft_integrator=scopus

[25] Zhou, Y., Li, W., Cheng, K., Shi, G., & Schonfeld, P. (2025). Automatic ship collision avoidance algorithm based on AIS data processing and improved DWA algorithm. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, 11(3), Article 04025030.

<https://ascelibrary.org/doi/10.1061/AJRUA6.RUENG-1525>

[26] Hung, T.-E., & Chang, C.-C. (2025). Evaluating the mental workload of watch officers during maritime navigation training courses. *Applied Ergonomics*, 128, Article 104560.

<https://www.sciencedirect.com/science/article/abs/pii/S0003687025000961?via%3Diuhub>

[27] Ammar, M., & Khan, I. A. (2024). Cyber attacks on maritime assets and their impacts on health and safety aboard: A holistic view. *arXiv preprint arXiv:2407.08406*. https://arxiv.org/abs/2407.08406?utm_source=

[28] Wang, J., Fan, H., Chang, Z., & Lyu, J. (2025). Unleashing data power: Driving maritime risk analysis with Bayesian networks. *Reliability Engineering and System Safety*, 264, Article 111310.

<https://www.sciencedirect.com/science/article/abs/pii/S0951832025005113?via%3Diuhub>

[29] Zhao, L., Xu, M., Liu, L., Bai, Y., Zhang, M., & Yan, R. (2025). Intelligent shipping: Integrating autonomous maneuvering and maritime knowledge in the Singapore-Rotterdam Corridor. *Communications Engineering*, 4(1), Article 11. <https://www.nature.com/articles/s44172-025-00346-0>

[30] Menges, D., Von Brandis, A., & Rasheed, A. (2024). *Digital twin of autonomous surface vessels for safe maritime navigation enabled through predictive modeling and reinforcement learning* (Version 2). arXiv. https://arxiv.org/abs/2401.04032?utm_source=

[31] Rabus, T. (2024). Handling of external risks, including launch and re-entry events, in the aviation and maritime sector. *Journal of Space Safety Engineering*, 11(4), 673–680. https://www.sciencedirect.com/science/article/pii/S2468896724000491?pes=vor&utm_source=scopus&getft_integrator=scopus

[32] Pan, W., Fan, J., Xie, X.-L., & Li, M. (2025). Theoretical research and system design of ship navigation guidance for the local temporary prohibited navigation area. *Scientific Reports*, 15(1), Article 11801. <https://www.nature.com/articles/s41598-025-95780-7>

[33] Liu, X., & Yuen, K. F. (2025). A systematic review on artificial intelligence applications in seaports – a network analysis approach. *Expert Systems with Applications*, 289, Article 128309. <https://www.sciencedirect.com/science/article/abs/pii/S0957417425019281?via%3Dihub>

[34] Nakashima, T., Kureta, R., & Khastgir, S. (2025). Addressing systemic risks in autonomous maritime navigation: A structured STPA and ODD-based methodology. *Reliability Engineering and System Safety*, 261, Article 111041. https://www.sciencedirect.com/science/article/pii/S095183202500242X?pes=vor&utm_source=scopus&getft_integrator=scopus

[35] Qi, Y., Yang, J., Bai, A., & Liu, J. (2025). A method for real-time detection of vessel abnormal behavior based on CNN-LSTM. *Expert Systems with Applications*, 288, Article 128303. <https://www.sciencedirect.com/science/article/abs/pii/S0957417425019220?via%3Dihub>

[36] Berg, H. S., Menges, D., Tengesdal, T., & Rasheed, A. (2025). Digital twin syncing for autonomous surface vessels using reinforcement learning and nonlinear model predictive control. *Scientific Reports*, 15(1), Article 9344. <https://www.nature.com/articles/s41598-025-93635-9>

PROBLEMS OF RELATIONS WITH THE EURASIAN ECONOMIC UNION

Levan Gvarishvili

Assistant Professor of Batumi Navigation University

Mirza Suknishvili

Assistant Professor of Batumi Navigation University

Giorgi Abashidze

Assistant of Batumi Navigation University

Abstract. The article examines the further expansion and deepening of transport and logistics cooperation within the EAEU, which faces several obstacles. These obstacles are categorized into two groups: infrastructural and institutional. According to the author, the current state of transport and logistics infrastructure hampers cooperation with the EAEU because it cannot fully address the EAEU's internal integration issues and cannot compete effectively in the globalized economy.

Keywords: Eurasian Economic Union, infrastructure challenges, institutional challenges, logistical cooperation.

Introduction. Infrastructure problems include: (i) the low level of development of the EAEU transport and logistics market; (ii) the inefficiency of the existing EAEU transport, warehousing, customs and management infrastructure; (iii) the persistent global lack of competitiveness of the EAEU transport and logistics complex.

Discussion. The main institutional problems are based on the fragmented nature of the coordinated (harmonized) transport policy of the EAEU and the lack of an effective mechanism for maintaining the competitiveness of railway and road transport of the EAEU countries in this context.

The high share of 1 and 2 PL providers in the EAEU transport and logistics market, all other things being equal, indicates its underdevelopment in terms of added value created and qualitative involvement, which generally has a negative impact on the EAEU economy. Thus, about 68% of the total volume of transport and logistics in the EAEU is carried out by the transport and logistics departments of enterprises, and the share of transport and logistics costs in the final cost of goods for the EAEU consumer is 20-25% (sometimes reaching 30%), while the world average is 11%, in the EU 11%, in the USA 10%, in China 14%.

Another indicator indicating the underdevelopment of the EAEU transport and logistics market is the low level of containerization of transport and logistics operations. Transportation of goods in containers allows saving time on loading and

unloading operations, which ultimately leads to a reduction in the price of the product for the end user.

Today, the level of containerization of global dry cargo, including consumer goods and automobiles, is on average 50-60%, while in the EAEU it barely reaches 5%, including about 3% in international traffic. Per 1,000 people, the level of containerization of transport in the EAEU is 37 containers against 127 units.

In its current form, the transport and logistics infrastructure cannot adequately support the current pace of integration. Under the transport and logistics infrastructure of the EAEU we mean the entirety of the transport infrastructure; that is, technical and mobile equipment, as well as stationary components - rail facilities, warehouse infrastructure, i.e. warehousing systems, customs infrastructure, conditions for the rapid completion of customs formalities and management infrastructure; In addition, networks of transport and logistics centers (TLC) on the external border of the EAEU and in the EAEU hub centers. The weakness of the infrastructure component of Eurasian integration, including transport, warehousing, customs, management, telecommunications, etc., in the long term may play the role of a drag on Eurasian integration, as well as the maintenance of non-tariff barriers in bilateral trade.

The EAEU transport infrastructure is characterized by a high degree of wear and tear of the material and technical base. More than 70% of the transport infrastructure is morally or technically obsolete, which puts the issue of its modernization at the top of the list of priorities for EAEU macro-integration. Among the leading countries (Russia, Belarus, Kazakhstan), the issue of modernizing the existing infrastructure is particularly acute in Kazakhstan, which will need \$50 billion to upgrade it by 2030. Significant wear and tear of the main elements of the infrastructure has been observed in Kazakhstan's railway transport - 70%, including: rolling stock - 71%, access roads - 85%, vehicles - 64%, power supply equipment - 62%, automation and communication equipment - 80%¹³⁹. In Belarusian road transport, on the contrary, a rapid renewal of the country's truck fleet is underway. Today, more than 50% of trucks comply with Euro-4 and Euro-5 environmental standards, which is the best indicator in the EAEU, and about 37% of vehicles have been in operation for less than three years.

In its current form, the region's warehouse infrastructure also hinders the effective functioning of the EAEU economy. EAEU warehouses are mainly focused on processing goods that do not require special storage conditions, such as mineral products, industrial semi-finished products and agricultural raw materials, and are located in large industrial centers and capitals of the EAEU countries. In this regard, the main function of the warehouse becomes the distribution function, i.e. the distribution of commodity flows from the center to the regions, creating an insignificant amount of added value, while the consolidation function, i.e. the

comprehensive service of working with cargo from receiving cargo in the warehouse to sending it to its destination, including processing, consolidation, packaging, labeling, etc., is presented insignificantly.

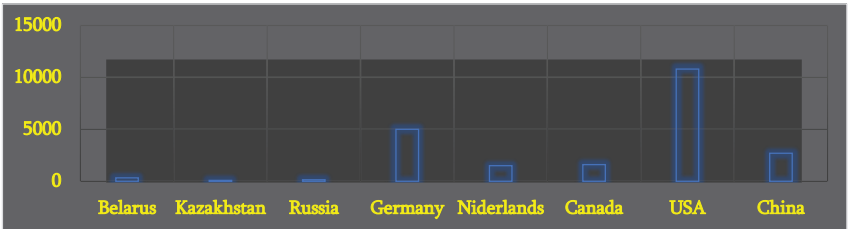
According to our estimates, the share of Class A warehouses with the highest infrastructure in the EAEU territory is no more than 30% of the total number of warehouses.

The customs infrastructure of the EAEU as a whole ensures the functioning of a single customs territory, but is characterized by a low level of development of the institutions of customs representation and authorized economic operators, which are designed to ensure the effective interaction between foreign trade participants and customs authorities. The practice helps simplify and accelerate customs procedures for exports, imports, and transit, reducing the share of transport and logistics costs in the final cost of goods.

Belarus leads in the number of registered AEOs among the EAEU countries. According to this indicator, the EAEU countries significantly lag behind the EU countries, NAFTA, and China (Diagram 1).

At the same time, the development of the EAEU customs infrastructure is hampered by the absence of a Unified EAEU Customs Code, the adoption of which is hindered by persistent disagreements among the contracting parties over organizational and practical adaptation. For example, according to the commitments made by Kazakhstan upon accession to the WTO, preferential conditions received by Kazakh importers within the WTO before the CTT may lead to unhindered re-export of goods from the territory of Kazakhstan to the markets of its partners in the EAEU, which contradicts the principles of a single customs territory.

Diagram 1. Number of registered AEOs¹ in the EAEU, NAFTA countries, and China



Source: Khapilin S. “Development of Eurasian Economic Integration Based on the Modernization of the Customs Regulation Mechanism” Dissertation submitted for the degree of Doctor of Economic Sciences

¹ AEO (Authorized Economic Operator) - Authorized Economic Operator, a legal entity that is included in the Register of Authorized Economic Operators and uses special simplifications in the customs territory.

Thus, the agreements within this union are subject to compliance with external conditions and agreements. Therefore, even if other conditions are met, this particular condition makes relations with the EAEU countries quite difficult.

Another piece of evidence of the low level of development of the EAEU transport and logistics infrastructure is the lack of modern transport and logistics centers (TLCs), both at the external borders and in hub centers within the EAEU. In terms of the number of operating TLCs, the EAEU noticeably lags behind the EU. According to our estimates, currently about 30 international and regional TLCs operate in the EAEU, and more than 100 in the EU. In terms of country, there is one TLC located in Yerevan, Armenia, five TLCs in Belarus - in Brest, Gomel and Minsk region, in Kazakhstan there are seven TLCs - in Astana (the largest in Central Asia), Shymkent, Aktau, Aktobe, St. Dostyk and the Khorgos border crossing, in Kyrgyzstan there are two TLCs - in Bishkek and the village of Sokuluk, in Russia there are about sixteen TLCs - in Moscow and Moscow region, St. Petersburg and Leningrad region, Novosibirsk, Ufa, Kazan, Chelyabinsk, Vladivostok, Pskov and others.

The current volume of financing for infrastructure construction in the EAEU averages 2-2.5% of GDP, while the amount of financial injections required to ensure the proper functioning of the economy should be at least 4.5%.

Thus, the transport and logistics infrastructure functions to a limited extent, is characterized by significant depreciation, the system operates with insufficient funding, which, all other things being equal, is unlikely to be able to maintain the given pace of expansion and deepening integration.

The main institutional obstacle to integration is the fragmented nature of the EAEU's coordinated transport policy, which is not distinguished by the systematicity of decisions, even in the rail and road transport modes. The absence of comprehensive unified rules and regulations for the EAEU transport and logistics market hinders the liberalization of the supply process, its quality improvement, adequate pricing and, consequently, the increase in the overall efficiency of the economic component of Eurasian integration.

The main institutional problems of integration in the railway transport regime are the lack of coordinated approaches of the EAEU countries to create the most favorable organizational and economic conditions and implement transit throughout the territory.

The primary difficulty in further institutionalizing the use of the EAEU unified railway tariff for transit transport is that transit transportation from a third country to a third country through the territory of the EAEU is still regulated within the framework of the CIS tariff policy. At the same time, the existing transport policy of the EAEU does not contain provisions on stimulating the use of CIM/SMGS railway consignment notes during transit on the territory of the EAEU, which generally slows down the

process.

According to the author, the potential for the use of CIM/SMGS consignment notes, which allows reducing the number of railway wagons at the transit border from three days to 1.5 hours, is currently used in the EAEU by less than 30%.

The lack of unified EAEU technical regulations and standards in the field of railway transport safety, their environmental friendliness, mandatory certification procedures for vehicles, as well as unified requirements for railway infrastructure.

The main institutional obstacles to integration in road transport are: (i) persistent difficulties in switching to electronic registration of cross-border road transport; (ii) dominance of the Russian segment of the EAEU road transport market; (iii) dominance of Russian companies and the absence of an effective mechanism to ensure the competitiveness of road transport for Armenian, Belarusian, Kazakh and Kyrgyz companies.

The effective functioning of road checkpoints on the external border of the EAEU is possible only if their transport, logistics and customs infrastructure are clearly interconnected, but the mechanism for this is not yet fully understood. It has been established, for example, that the transition of cross-border movement of goods to electronic customs clearance will reduce customs procedures by 30-35%, which will ultimately lead to a reduction and optimization of delivery times. The lack of unified regulatory standards in the transport and logistics sector and the continued existence of non-tariff restrictions in mutual trade between EAEU countries also led to the short-term restoration of customs control at Russian border crossings with Belarus and Kazakhstan, which contradicts the principle of the “four freedoms”. The lack of binding mechanisms regulating a coordinated transport policy allowed Russia, unilaterally, without coordinating this decision with its partners, to suspend the use of TIR Carnets 150 on its territory, which caused a “domino effect” in the EAEU countries and did not reach the pre-crisis level.

Apparently, this step by the Russian authorities was an attempt to create its own national transit standards, in particular, a system of cash deposits and financial guarantees presented at each crossing of the Russian customs border, which would ultimately lead to an increase in revenues to the national budget. This change in the rules led to an increase in delivery times by an average of 30-40%, and Russia lost up to 15% of the annual volume of international road transport (about 70 billion rubles; 720 million USD). Such a step by the Russian side significantly affected Kazakhstan's road transport industry, which handles 75% of all imported road transport from the European Union through Russian territory. Thus, the average cost of delivery increased by 500 thousand US dollars, which makes Kazakh road transport uncompetitive compared to railways, which for Kazakhstan amounts to 100 million dollars.

Conclusion

Thus, the transport and logistics infrastructure in its current form hinders the development of transport and logistics cooperation with the EAEU, since it is unable to fully address the internal problems of EAEU integration and is powerless to cope with competition in the globalized market.

References:

1. Green Alternative. (2013, June). "Evaluation of the Effectiveness of the Implementation of the Environmental and Sustainable Development Part of the European Neighborhood Policy EU-Georgia Action Plan 2007-2012";. (Research). Tbilisi, Georgia: Green Alternative.
2. Constantinescu, C., Mattoo, A., & Ruta, M. (2026). Trade Developments in 2026: Policy Uncertainty Weighs on World Trade. World Bank Group. Retrieved from <http://documents.worldbank.org/curated/en/228941487594148537/pdf/112930-v1-revised-PUBLIC-1706109-Global-Trade-Watch-Report-Web.pdf>
3. CRRC-Georgia and the Partnership for Road Safety Foundation. (June 2024). Safe Mobility Options for Passengers – A Policy Paper. Tbilisi: East-West Management Institute (EWMI) ACCESS Project;
4. Gitolendia, B. (2018). "Ways of approximation and further compatibility of the Georgian transport system with the European and International Standards". Tbilisi: Paata Gugushvili Institute of Tbilisi Iv.Javakhishvili State University.
5. Lashkhi, T., Patariaia, G., & Gabrielashvili, A. (2024). "Georgian Railway LLC – Drafting an Analytical Report";. Office of the State Minister of Georgia on European and Euro-Atlantic Integration. Tbilisi: Project of Open Society Georgia Foundation.
6. WTO. (2024, January). World Trade Statistical Review 2024. 1, 174. NY, NU, USA. Retrieved from https://www.wto.org/english/res_e/statis_e/wts2019_e/wts19_toc_e.htm
7. Avdaliani, E. (2019, 05 02). Georgia and the Great Silk Road: Myth or Reality? . Tbilisi, Georgia: Forbes Georgia. Retrieved from <https://forbes.ge/news/6161/saqarTvelo-da-abreSumisdidi-gza>
8. Bliadze, M., Sulaberidze, L., & Sharashidze, L. (2024). Development of transport and transit corridors at the international level and its importance. Social economy: current problems of the 21st century (N 3).
9. Government of Georgia. (2025). Government program "Only with peace, dignity, prosperity towards Europe". Tbilisi: Parliament of Georgia. Retrieved from https://www.gov.ge/files/90372_90372_536784_372256.pdf
10. Ministry of Regional Development and Infrastructure of Georgia. (2025). Ministry

of Regional Development and Infrastructure of Georgia. (S. R. Ministry., Ed.)
Tbilisi, Georgia. Retrieved from
http://www.mrdi.gov.ge/sites/default/files/kaxetis_regionis_ganvitarebis_strategia_20_14-2021_clebistvis_0.pdf

11. Government Program “Towards Europe Only with Peace, Dignity, and Prosperity”.
https://www.gov.ge/files/90372_90372_536784_372256.pdf
12. Boris Gitolendia – Analysis of Intermodality Issue of Transportation System of Georgia – International Conference “Technological Innovations for Sustainable Society,” Vilnius College of Technologies and Design, Technical Faculty, – Vilnius, Lithuania – 2018;
13. Trade and Development Report 2019. Financing a Global Green New Deal. Report by the Secretariat of the United Nations Conference on Trade and Development. United Nations Publications, 2024. 173 p.
https://unctad.org/en/PublicationsLibrary/tdr2019_en.pdf (accessed 29.02.2024).
14. Trade: Merchandise exports (current US\$). The World Bank. Available at:
<https://data.worldbank.org/topic/trade> (accessed 29.02.2024).

FOR AUTHOR USE ONLY

BUSINESS COMMUNICATIONS AS A FORMULA FOR EFFECTIVE BUSINESS RELATIONS

Tamar Diasamidze

Associate professor at Batumi Navigation University

Tatia Tsetskhladze

Assistant professor at Batumi Navigation University

Abstract. Business communication is a critical component of modern organizational functioning, directly influencing performance, collaboration, and decision-making. It is recognized not merely as the exchange of information but as a structured, systematic process that can be conceptualized as a formula for achieving organizational effectiveness. This formula integrates verbal and non-verbal interaction, clarity of expression, active listening, technology-mediated communication, and cultural awareness. Systematic application of these dimensions helps organizations minimize misunderstandings, strengthen cooperation, and foster trust both internally and externally. In today's globalized and digitally driven business environment, effective communication increasingly relies on technological platforms, requiring precision, professionalism, and adaptability. Multicultural workplaces demand sensitivity to diverse perspectives and practices, promoting inclusivity and mutual respect. Strategic integration of clarity, empathy, and communication tools enables organizations to cultivate sustainable professional relationships and improve overall performance. Effective business communication also encompasses relational and ethical dimensions, reinforcing organizational culture, employee motivation, and leadership effectiveness. Moreover, it underpins interactions with external stakeholders, where trust, credibility, and transparency are essential. Consequently, communication functions as both an operational necessity and a strategic advantage, supporting long-term organizational success, innovation, and sustainable growth in an interconnected global economy.

Keywords: Business communication; organizational success; communication formula; globalization; cultural awareness.

Introduction and review of literature

In the contemporary world, effective communication has become a cornerstone of organizational success. The rise of globalization, technological innovation, and multicultural work environments has elevated communication to a strategic function that determines how efficiently an organization can operate internally and externally. Business communication, in particular, serves not only as a vehicle for information exchange but also as a means of fostering trust, cooperation, and

productivity within and across enterprises (Smith, 2019). The essence of effective communication lies in its ability to convey messages clearly, reduce misunderstandings, and facilitate decision-making. When communication fails, the consequences can range from minor operational inefficiencies to large-scale organizational crises.

The main objective of this research is to explore the role of business communication in achieving effective communication in modern organizations. It aims to identify the mechanisms by which communication enhances performance, the challenges that hinder its efficiency, and the strategies organizations employ to overcome these barriers. Furthermore, this study seeks to evaluate how communication practices have evolved over the last decade, shaped by digitalization, remote work, and cultural diversity. The research scope encompasses both the theoretical and practical aspects of communication, focusing on its psychological, linguistic, and technological dimensions.

Literature Review

Business communication is commonly defined as the process of creating, sharing, and interpreting messages within an organizational context to achieve common goals (Bovee & Thill, 2021). It involves both verbal and nonverbal forms of expression. Verbal communication refers to spoken or written words used to convey information—such as meetings, reports, presentations, or emails—while nonverbal communication includes tone of voice, facial expressions, gestures, posture, eye contact, and even physical distance between communicators (Knapp et al., 2018). These two modes work together to shape meaning and influence how messages are perceived. For instance, an assertive tone or confident body language can enhance the persuasive power of a verbal message, whereas conflicting nonverbal cues (e.g., avoiding eye contact while agreeing) can create confusion or distrust (Guerrero & Floyd, 2020).

In business settings, nonverbal communication often determines the quality of interpersonal relations. According to Mehrabian's theory, a large portion of communicative meaning is derived from nonverbal signals rather than words themselves (Mehrabian, 2019). Managers and team leaders, therefore, rely not only on what they say but also on how they say it—projecting authority, empathy, or confidence through tone and gesture. In virtual environments, where nonverbal cues are limited, communicators must compensate by crafting clearer and more structured verbal messages to ensure understanding (Nguyen et al., 2022).

Scholars have widely recognized the importance of communication in business contexts. Tourish (2020) emphasizes that leadership effectiveness is strongly tied to communicative competence; leaders who communicate vision and feedback effectively

inspire higher employee engagement and organizational loyalty. Similarly, Clampitt (2019) highlights that clear, open communication channels contribute to better conflict management and innovation, whereas poor communication leads to distrust, errors, and reduced performance.

Modern literature underscores that communication extends beyond information transfer—it is a dynamic, interactive, and relational process (Richmond & McCroskey, 2018). However, despite its importance, effective communication faces numerous barriers that impede clarity and understanding.

Communication barriers refer to factors that distort or obstruct the transmission and interpretation of messages. These can be classified into several categories:

1. **Linguistic Barriers** – Language differences, jargon, slang, or ambiguous terminology often lead to misinterpretations. In multinational companies, employees may use English as a lingua franca, but varying proficiency levels and cultural nuances can lead to misunderstandings (Robinson, 2021). For example, idiomatic expressions or metaphors may carry different meanings across cultures, leading to confusion or even offense.
2. **Cultural Barriers** – Culture influences communication style, etiquette, and expectations. High-context cultures (e.g., Japan, the UAE) rely heavily on implicit messages and shared understanding, while low-context cultures (e.g., the U.S., Germany) prefer direct and explicit communication. Failure to recognize these differences can create tension, misalignment, and reduced collaboration (Hall, 2018).
3. **Psychological Barriers** – Emotions, attitudes, and personality traits often interfere with message interpretation. Stress, prejudice, fear of criticism, or lack of confidence may prevent individuals from expressing themselves openly (Putnam & Nicotera, 2020). Additionally, selective perception—the tendency to interpret information in line with one’s beliefs—can distort reality and hinder productive dialogue.
4. **Technological Barriers** – The digitalization of communication has brought both opportunities and challenges. While emails, instant messaging, and video calls enhance speed and global reach, they can also lead to information overload, shorter attention spans, and a lack of human warmth (Nguyen et al., 2022). Misuse of technology, poor connectivity, and cyber distractions often undermine effective communication in remote teams.
5. **Organizational Barriers** – Hierarchical structures, unclear reporting lines, or a lack of feedback mechanisms may block upward or lateral communication. Employees may hesitate to share ideas or problems with higher management due to fear or a lack of trust (Keyton, 2019). Transparent and decentralized

communication systems have been shown to increase innovation and employee satisfaction.

The consequences of these barriers can be severe. Miscommunication can lead to delays, errors, conflicts, and even financial loss. Conversely, organizations that invest in communication training, intercultural competence, and emotional intelligence development tend to achieve higher operational efficiency and morale (Goleman, 2018; Rahim, 2020). Furthermore, business communication plays a critical role in corporate reputation and customer relations. Transparent and ethical communication strengthens public trust and brand credibility (Men & Bowen, 2017).

Overall, the literature review suggests that effective business communication is not a simple linear process but a complex, adaptive system influenced by interpersonal, organizational, and technological variables. Successful organizations integrate both verbal and nonverbal channels, acknowledge communication barriers, and cultivate emotional and cultural awareness to enhance performance and sustain long-term success.

Methodology

This study adopts a mixed-methods approach, combining both qualitative and quantitative methods to ensure a comprehensive understanding of the phenomenon. The choice of this methodology is based on the recognition that business communication involves both measurable behaviors—such as message frequency, feedback rate, and productivity—and interpretive dimensions, such as meaning construction, perception, and interpersonal dynamics. Therefore, integrating statistical data with interpretive analysis provides a more holistic perspective on how communication influences organizational effectiveness (Creswell & Plano Clark, 2018).

2.1 Research Design

The research uses a descriptive and analytical design to identify the key determinants of effective business communication and examine how these determinants affect performance outcomes (Robson & McCartan, 2016). Primary and secondary data are collected to combine empirical evidence and theoretical insights (Flick, 2018).

2.2 Participants and Sampling

The study's participants include 50 employees and 10 managers from medium and large-sized enterprises across sectors such as finance, marketing, and IT. Purposive sampling was employed to include individuals actively involved in business communication processes (Etikan et al., 2016).

2.3 Data Collection Methods

1. **Surveys:** Online questionnaires captured quantitative data on communication frequency, clarity, and employee satisfaction.
2. **Semi-structured interviews:** Conducted with managers and employees to gather qualitative insights on communication challenges, emotional intelligence, and leadership styles (Braun & Clarke, 2019).
3. **Document analysis:** Review of company policies, manuals, and templates to understand formal communication structures (Flick, 2018).

2.4 Data Analysis Procedures

Quantitative data were analyzed in SPSS to examine frequencies, percentages, and correlations (Field, 2018). Qualitative data were coded thematically (Braun & Clarke, 2019).

2.5 Reliability and Ethical Considerations

Reliability was ensured through standardized procedures and triangulation (Creswell & Plano Clark, 2018). Ethical principles were rigorously applied (APA, 2020).

Results

The results of this study provide a comprehensive understanding of the role of business communication in effective organizational functioning. Analysis of the data—integrating quantitative survey results, qualitative interview narratives, and organizational document reviews—indicates that communication operates not merely as a procedural or operational tool but as a strategic organizational resource that underpins efficiency, alignment, and productivity across all hierarchical levels (Tourish, 2020; Clampitt, 2019). Survey results reveal that a significant majority of employees perceive clear communication as essential to achieving work objectives, highlighting its role in reducing misunderstandings and ensuring alignment with organizational goals. Interviews corroborated these findings, showing that structured communication channels facilitate mutual understanding, trust, and collaboration among colleagues and between management and staff.

The findings also demonstrate that communication is a multidimensional process encompassing both verbal and nonverbal components. Verbal communication through meetings, reports, presentations, and emails ensures that instructions, expectations, and organizational policies are clearly transmitted. At the same time, nonverbal cues, such as tone of voice, body language, gestures, and facial expressions, complement verbal messages by reinforcing meaning, expressing organizational culture, and shaping

interpersonal trust (Knapp et al., 2018; Guerrero & Floyd, 2020). Alignment between verbal and nonverbal signals significantly enhances message reception and credibility, whereas incongruence often leads to confusion, reduced engagement, and diminished cohesion.

Leadership effectiveness emerged as a recurring theme, with managers who communicate clearly, provide structured guidance, and actively practice empathetic listening, fostering higher levels of employee engagement, trust, and productivity. Effective communication also promotes innovation, as employees are more likely to share ideas and propose solutions in environments where communication is open, feedback is constructive, and managerial responses are timely. Barriers to effective communication, including linguistic, cultural, psychological, technological, and organizational obstacles, were identified, and proactive interventions were shown to improve performance and satisfaction significantly (Hall, 2018; Goleman, 2018; Rahim, 2020; Nguyen et al., 2022; Clampitt, 2019).

Conclusions

This study underscores the pivotal role of business communication as a strategic resource that directly influences organizational efficiency, cohesion, and long-term sustainability. Effective communication integrates verbal and nonverbal elements to create a coherent, reliable, and transparent flow of information (Knapp et al., 2018; Guerrero & Floyd, 2020). By fostering clarity, mutual understanding, and trust, communication catalyzes enhanced employee engagement, leadership effectiveness, and innovation (Goleman, 2018; Rahim, 2020; Clampitt, 2019).

The absence of clear communication can result in misunderstandings, misaligned tasks, reduced collaboration, and lower morale, compounded by linguistic, cultural, psychological, technological, and organizational barriers (Hall, 2018; Nguyen et al., 2022; Keyton, 2019). Organizations that systematically cultivate communication through training, feedback, leadership development, and digital optimization achieve higher efficiency, innovation, and resilience (Tourish, 2020; Clampitt, 2019; Hall, 2018).

Overall, business communication functions as both an operational tool and a strategic asset, essential for aligning objectives, fostering collaboration, and enhancing organizational sustainability in competitive markets.

References

1. Clappitt, P. G. (2019). *Communicating for managerial effectiveness: Problems, strategies, solutions* (6th ed.). SAGE Publications.
2. Goleman, D. (2018). *Emotional intelligence: Why it can matter more than IQ* (20th anniversary ed.). Bantam Books.
3. Guerrero, L. K., & Floyd, K. (2020). *Nonverbal communication in close relationships*. Routledge.
4. Hall, E. T. (2018). *Beyond culture* (2nd ed.). Anchor Books.
5. Knapp, M. L., Hall, J. A., & Horgan, T. G. (2018). *Nonverbal communication in human interaction* (9th ed.). Cengage Learning.
6. Keyton, J. (2019). *Communication and organizational culture: A key to understanding work experiences*. SAGE Publications.
7. Nguyen, T., Chen, W., & Li, X. (2022). Digital communication and organizational efficiency: Overcoming technological barriers. *Journal of Business Communication*, 59(2), 145–167. <https://doi.org/10.1177/23294884211012345>
8. Putnam, L. L., & Nicotera, A. M. (2020). *Building theories of organization: The constitutive role of organization*. Routledge.
9. Rahim, M. A. (2020). *Managing conflict in organizations* (5th ed.). Routledge.
10. Richmond, V. P., & McCroskey, J. C. (2018). *Organizational communication for survival: Making work, work* (5th ed.). Pearson.
11. Robinson, S. (2021). Linguistic diversity and communication effectiveness in global organizations. *International Journal of Business Communication*, 58(4), 401–422. <https://doi.org/10.1177/2329488420981234>
12. Tourish, D. (2020). *The dark side of transformational leadership: A critical perspective*. Routledge.
13. Clappitt, P. G., DeKoch, R. J., & Cashman, T. (2021). *A communication framework for organizational effectiveness*. Routledge.
14. Gibbs, J. L., Sivunen, A., & Boyraz, M. (2020). Virtual teams: A review of current literature and directions for future research. *International Journal of Management Reviews*, 22(3), 437–463. <https://doi.org/10.1111/ijmr.12229>
15. Robinson, S., & Harvey, M. (2022). Cross-cultural communication barriers in multinational corporations. *Journal of International Business Studies*, 53(5), 789–812. <https://doi.org/10.1057/s41267-021-00441-x>

PROSPECTS FOR REALIZING THE POTENTIAL OF THE EURASIAN ECONOMIC UNION IN THE SYSTEM OF INTERNATIONAL TRANSPORT CORRIDORS

Maia Chechelashvili

Doctor of Economics, Associate Professor of GTU

George Gabedava

Professor at Batumi Navigation University

Tengiz Aphkhazava

Professor at Batumi Navigation University

Nino Tchilaia

Associate Professor at Batumi Navigation University

Abstract. The article explores the strategic geographic position of the Eurasian Economic Union at the intersection of major trade routes, which gives it significant transit potential within the global transport network. It highlights that the transit potential of the Eurasian Economic Union is currently underutilized due to the region's transport and logistics infrastructure's weak competitiveness and the lack of a comprehensive, unified transport system. The author argues that underutilizing this transit potential denies member countries an additional source of government revenue, thereby impeding their economic growth.

Keywords: transit potential of the Eurasian Economic Union, transport corridor, logistics infrastructure.

Introduction

It seems that developing the EAEU ITC to create a modern transit system can deepen transport and logistics cooperation in the EAEU, one of the areas of Eurasian economic integration, and, as a result, increase competitiveness. The comprehensive development of the EAEU transit infrastructure can improve internal communications and, consequently, increase bilateral trade volume, attract investment, and enable large cross-border projects. Effective transit communications can also ensure the economic unity of the EAEU member states and strengthen ties among the countries' producers, directing their orientation toward cooperation within new multimodal transport value chains and integrated service provision. According to OECD calculations, a 10% increase in transport productivity leads to a 0.8% increase in GDP.

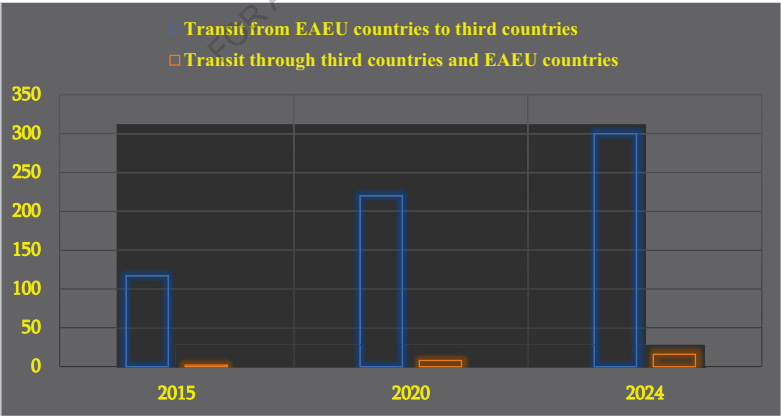
Discussion

The structure of EAEU transit communications is dominated by traffic from EAEU countries to third countries through the EAEU territory (internal transit), while transit from third countries to third countries through the EAEU territory accounts for only 3.5% of the total transit volume. In the context of duty-free transportation within the single customs territory, transit from one endpoint to another is the main source of budget revenue for transit countries. Overall, EAEU integration processes have contributed to the growth of end-to-end transit, with the volume increasing fourfold from 2015 to 2020, and the 2025 growth forecast is up to 16 million tons (Figure 1).

Today, less than 1% of the total volume of international cargo transportation between East and West passes through the territory of the EAEU, whereas in 1982 the USSR accounted for 20% of that figure.

According to UNCTAD, in 2024, trade in the region amounted to 800 billion dollars, and by 2027, it is expected to grow to 1.2 trillion dollars, which is equivalent to 240 million tons of cargo, of which 170 million tons (about 800 billion dollars) will come from the EU's trade turnover with China. Up to 90% of trade between the Asia-Pacific countries and the EU is carried out via the Southern Sea Route via the Suez Canal. The annual volume of containerized sea freight from the EU to China is 4.5 million TEU, and in the opposite direction, 11.2 million TEU, and it takes an average of 35-40 days.

Diagram 1. Structure of transit shipments in the territories of the EAEU countries, million tons



Source: National Transport Agencies of EAEU Countries: URL:
<http://www.armstat.am>, <http://www.belstat.gov.by>, <http://www.stat.gov.kz>,
<http://www.stat.kg>, <http://www.gks.ru>

In the future, the Suez Canal is likely to be unable to cope with the growing flow of cargo, thereby freeing up capacity for the EAEU. The cost of land transportation within the EAEU is on average twice as high as sea transportation, but the main competitive advantage of land transit within the EAEU is its speed, which is two to three times higher than sea transportation. In this regard, land transit within the EAEU is still economically justified only for goods for which speed of delivery is a key requirement (for example, goods with high added value or perishable food products, etc.). Thus, the primary task of transport and logistics cooperation with the EAEU in the field of transit should be to create effective tools for the “rerouting” of maritime cargo flows in the EU-China direction to the land territory of the EAEU and the formation of alternative competitive routes for the transport supply of Eurasia.

The developing system of transport corridors of the EAEU consists of two Eurasian corridors - “East-West” and “North-South”, which are connected, respectively, to the Pan-European corridors No. 2 and No. 9. The East-West ITC originates in the ports of Nakhodka and Vladivostok, follows the Trans-Siberian railway route to Moscow, and then joins the Pan-European corridor No. 2 via Minsk and Warsaw to reach Berlin. The North-South Corridor starts in Helsinki and then coincides with the Pan-European Corridor No. 9 - through the ports of St. Petersburg and the Leningrad region to Astrakhan, and then through Iran to the coast near the port of Bandar Abbas, in the direction of the Persian Gulf and India.

The Eurasian East-West Corridor is focused on the transit transportation of cargo not only from China, but also from Japan, South Korea, Indonesia, Malaysia and Singapore to the European Union. Russia and Kazakhstan are showing great interest in the development of this corridor, and in this particular context, in the fight for transit cargo, they are both partners and competitors. The transit potential of the EAEU in this direction is more than 1 million TEU, and the annual capitalization of container transit alone is more than 2 billion dollars. Today, according to experts from the International Discussion Club of Experts, it is only 30-35% loaded.

It seems that in the case of full-fledged loading, competition for transit cargo between the Russian and Kazakh segments may intensify, but in the long term, the existence of Russian and Kazakh transit options will contribute to the policy of equalizing tariffs for land transit transportation on the territory of the EAEU, since rail transit is traditionally subsidized from the budget.

The core of the Russian section of the East-West ITC remains the Trans-Siberian Railway, which for a long time (since the 19th century) was the main land bridge between Europe and Asia. Transportation on the Trans-Siberian Railway allows for the passage of 8 thousand kilometers and shortens the delivery route from Europe to Asia, which is expressed in a saving of 10-20 days on transit. In 2024, the volume of

container traffic on the Trans-Siberian Railway amounted to 700 thousand TEU, which exceeds the transit from third countries and indicates significant advantages of internal transit. For the modernization of this transport highway, 562 billion rubles (6 billion USD) were allocated from the National Welfare Fund of Russia, the budget of JSC Russian Railways and state funds.

The multimodal status of the North-South Corridor of Eurasia should be strengthened by organizing ferry services with a maritime component of transport. It is planned to transform the ports of Olya and Aktau into the main maritime hubs of the corridor. However, the relatively low level of infrastructure development of both ports and their specialization in processing a limited range of cargoes prevents the creation of a competitive transport and logistics value chain in this direction. The existing infrastructure of the Olia port allows for the processing of 1.7 million tons of dry cargo annually, which is less than 5% of the shipping of the entire Caspian Sea segment. In 2024, the volume of cargo transportation in Ola amounted to about 300 thousand tons.

The port of Aktau is mainly focused on loading oil and oil products to Europe via the port of Baku. The main problem in implementing the Kazakhstan program is the redirection of part of the export flows to the EU, since the pipeline must either reach Europe through Russian territory, or use tanker transportation through Azerbaijan and Turkey. The reason for this is the underdevelopment of the Kazakh tanker fleet. The peculiarity of the port of Aktau lies in its shallow water (10 m, respectively, it can accept tankers with a dead weight of 3-5 thousand tons), while a tanker of 13 thousand tons is considered optimal for this route.

By 2015, the Kazakh tanker fleet consisted of 20 tankers, which is insufficient to transport 3.5 million tons of oil, so by 2028 it is planned to increase the number of tankers to 22 million tons, taking into account the planned throughput.

In addition, the multimodal trans-Caspian transit route China-Kazakhstan-Azerbaijan, which passes through the port of Aktau and is carried out by the container ship Nomad Express, is an example. Containers travel from China by rail to the port of Aktau, and then by ferry across the Caspian Sea to their final destination - the city of Kishli, near Baku. The average travel time is 5 days, which, given the transit potential of this direction, will bring significant transit revenue of 300 thousand TEU to Kazakhstan in the future.

Thus, the effective organization of transit along the developing North-South sections will allow the EAEU countries to become a connecting link in the strategically important and still incompletely opened Iranian and Indian directions.

Due to similar infrastructural limitations in the field of multimodality, in the “North-South” direction, in our opinion, Russia and Kazakhstan are more partners than competitors.

A special place in the expansion and deepening of transport and logistics cooperation in the EAEU through the creation of modern value chains in the transport and logistics industry is occupied by the Russian socio-economic project Trans-Eurasian Belt Razvitie (TEPR).

The project is based on the idea of creating an advanced development zone along the Trans-Siberian Railway and the BAM (Baikal-Amur Mainline), the central element of which is an integral infrastructure system - a multi-infrastructure that combines transport, telecommunications and energy into one gigantic whole system and subordinates them to a common development goal. In particular, this goal is a narrowly focused quantitative increase in transit freight traffic along the Trans-Siberian Railway, followed by a comprehensive socio-economic transition from a single industry to industrial management, in which rail transport is assigned a leading role.

This approach is generally correlated with the main task of Eurasian economic integration, which serves to establish cooperation in non-resource production in the EAEU economy.

TEPR is not just a transport corridor that allows the EAEU countries to use their transit potential. It serves the countries as a structured force for reindustrialization, using advanced technologies and creating industrial clusters both within the EAEU and along its eastern border and along the transport routes moving to the south. The “virus of infrastructure integration”, which is planned to be introduced into the EAEU economy, will ensure a comprehensive increase in the socio-economic indicators of the integrated countries, which, in turn, will strengthen their interest in further deepening the integration process.

Conclusion

Thus, the TEPR development vector, built into the system of developing transport corridors of Eurasia, can ensure the priority of the development of regional infrastructure of the EAEU over the national one. At the same time, the effective organization of internal and end-to-end transit within the territory of the EAEU within the framework of the East-West and North-South international transport corridors aims to ensure the economic unity of the integrated countries.

Effective transport and logistics cooperation for Georgia in both regional and transcontinental formats within the EAEU can become a source of deepening and expanding Eurasian economic integration through the development of multimodal transport and by increasing the quality of integration of the transport and logistics services provided. The transcontinental formats of the EU-EAEU-APR based on the East-West ITC and the EU-EAEU-Iran-India based on the North-South ITC will generally contribute to increasing the foreign economic and foreign policy role of the

EAEU, which is accompanied by rapid and complete globalization of the economy, optimization of the delivery of goods in time, and reduction of the share of transport and logistics costs in their final cost.

Georgia faces a difficult choice in this regard.

References:

1. “Green Alternative”. (2013, June). “Evaluation of the effectiveness of the implementation of the environmental protection and sustainable development part of the European Neighborhood Policy EU-Georgia Action Plan 2007-2012”.;. (Research). Tbilisi, Georgia: Green Alternative.
2. Constantinescu, C., Mattoo, A., & Ruta, M. (2026). Trade Developments in 2026: Policy Uncertainty Weighs on World Trade. World Bank Group. Retrieved from <http://documents.worldbank.org/curated/en/228941487594148537/pdf/112930-v1-revised-PUBLIC-1706109-Global-Trade-Watch-Report-Web.pdf>
3. CRRC-Georgia and the Partnership for Road Safety Foundation. (June 2024). Safe Mobility Options for Passengers – A Policy Paper. Tbilisi: East-West Management Institute (EWMI) ACCESS Project;
4. Gitolendia, B. (2018). “Ways of approximation and further compatibility of the Georgian transport system with the European and International Standards”. Tbilisi: Paata Gugushvili Institute of Tbilisi Iv.Javakhishvili State University.
5. Lashkhi, T., Pataraiia, G., & Gabrielashvili, A. (2024). “Georgian Railway LLC – Drafting an Analytical Report”.;. Office of the State Minister of Georgia on European and Euro-Atlantic Integration. Tbilisi: Project of Open Society Georgia Foundation.
6. WTO. (2024, January). World Trade Statistical Review 2024. 1, 174. NY, NU, USA. Retrieved from https://www.wto.org/english/res_e/statis_e/wts2019_e/wts19_toc_e.htm
7. Avdaliani, E. (2019, 05 02). Georgia and the Great Silk Road: Myth or Reality? . Tbilisi, Georgia: Forbes Georgia. Retrieved from <https://forbes.ge/news/6161/saqarTvelo-da-abreSumisdidi-gza>
8. Bliadze, M., Sulaberidze, L., & Sharashidze, L. (2024). Development of transport and transit corridors at the international level and its importance. Social Economy: Current Problems of the 21st Century (N 3).
9. Government of Georgia. (2025). Government Program “Towards Europe Only with Peace, Dignity, and Prosperity”. Tbilisi: Parliament of Georgia. Retrieved from https://www.gov.ge/files/90372_90372_536784_372256.pdf
10. Ministry of Regional Development and Infrastructure of Georgia. (2025). Ministry of Regional Development and Infrastructure of Georgia. (S. R. Ministry., Ed.)

Tbilisi, Georgia. Retrieved from

http://www.mrdi.gov.ge/sites/default/files/kaxetis_regionis_ganvitarebis_strategia_2014-2021_clebistvis_0.pdf

11. Government Program “Towards Europe Only with Peace, Dignity, and Prosperity”. https://www.gov.ge/files/90372_90372_536784_372256.pdf
12. Boris Gitolendia – Analysis of Intermodality Issue of Transportation System of Georgia – International Conference “Technological Innovations for Sustainable Society,” Vilnius College of Technologies and Design, Technical Faculty, – Vilnius, Lithuania – 2018;
13. Trade and Development Report 2019. Financing a Global Green New Deal. Report by the Secretariat of the United Nations Conference on Trade and Development. United Nations Publications, 2024. 173 p.
https://unctad.org/en/PublicationsLibrary/tdr2019_en.pdf (accessed 29.02.2024).
14. Trade: Merchandise exports (current US\$). The World Bank. Available at:

FOR AUTHOR USE ONLY

OPTIMIZING THE OPERATION OF SHIPS WITH THE USE OF ARTIFICIAL INTELLIGENCE SYSTEMS

Nugzar Bolkvadze

Assistant Professor of BNU

Ruslan Verdzhadze

Assistant Professor of BNU

Aram Bazaian

Assistant Professor of BNU

Levan Bolkvadze

Master-Mariner

Assistant Professor of BNU

George Gabedava

Professor of BNU;

Head of International Relations Service;

Abstract

The objective of this study was to empirically evaluate the effectiveness of artificial intelligence systems in optimizing the operation of commercial maritime vessels. The goal was to assess AI-driven improvements in fuel efficiency, voyage stability, and predictive maintenance accuracy. The methodology involved collecting and processing telemetry from 58 synchronized onboard measurement channels. These included temperatures, vibration metrics, gyroscopic data, trim and heel angles, and AIS/DGPS/radar signals. Data were sampled at 1-second intervals, filtered using the Hampel method, and aggregated into 3-minute frames. Baseline fuel oil consumption profiles were constructed using two-year historical data and polynomial regression adjusted for sea-state conditions. A hybrid deep learning model was developed to forecast vessel speed, fuel consumption, and stability. The experimental phase was conducted on 16 vessels—6 container carriers (3,000 TEU class) and 10 Handymax bulk carriers (40,000–55,000 DWT). These vessels completed 97 voyages between March 2023 and February 2024, with 45% of routes in the Black Sea and 55% in the North Sea. A validation campaign comprising 9,230 hours of simulator trials and real-world deployment tested the artificial intelligence model under variable sea states and scenarios involving AIS and DGPS disruptions. The results showed a 12.4% reduction in average fuel consumption and an 8.2% decrease in voyage duration. Ship stability improved, with roll amplitude reduced by 22%. Predictive maintenance algorithms achieved 95% accuracy, enabling early fault detection and reducing unscheduled downtime. Only three manual interventions were recorded during deployment, and course deviations remained below 1.3°. The study demonstrated substantial economic benefits, with estimated annual savings of USD 5.9 million. Financial modeling indicated a net present value of USD 7.4 million and an internal rate of return of 23%. An environmental analysis showed a 4.2% reduction in carbon intensity, supporting compliance with IMO CII standards. These findings substantiate the practical viability and sustainability of AI-based optimization in modern maritime logistics.

Keywords: Telemetry, hydrodynamics, forecasting, stability, validation, adaptation, sustainability, resilience.

Introduction

Modern maritime operations were characterized by increasing technological and operational complexity, as they simultaneously considered multiple variables: the technical condition of onboard systems, weather conditions, route dynamics, load levels, and regulatory requirements. Based on static rules and predetermined schedules, traditional control strategies lacked the necessary adaptability and failed to respond effectively to dynamic external environments. This was particularly evident in efforts to enhance energy efficiency, reduce greenhouse gas emissions, and minimize operational costs, where conventional management approaches no longer ensured sufficient precision or resilience.

The emergence of artificial intelligence (AI) has enabled dynamically adjusting vessel behavior in response to real-time operational conditions. In particular, the study by E. Artusi (2021) examined the application of deep reinforcement learning algorithms for vessel routing under weather constraints. While these models demonstrated the ability to adapt routes in response to environmental changes, the experiments were limited to simulation environments. They did not address the complexities of real-world, multi-criteria optimization in commercial fleets.

M. H. Moradi et al. (2022) contributed significantly to energy-saving strategies, proposing AI-based routing optimization algorithms to reduce fuel consumption and CO₂ emissions. Although the approaches yielded promising results in controlled trials, their applicability was geographically limited. They did not consider vessel stability factors or the risks associated with system failures during long-distance voyages.

Another direction focused on predictive maintenance. Z. Liu et al. (2023) developed digital twin architectures that used telemetry data to forecast wear and potential equipment failures. Although the models improved failure predictability, the study noted limited access to extensive real-world vessel data, which constrained model accuracy and hindered scalability across diverse vessel classes.

S. Thombre et al. (2022) explored situational awareness and environmental perception, proposing multimodal sensor fusion models integrating radar, AIS, and onboard video feeds. These technologies enhanced safety in autonomous navigation, but their integration into vessel energy management and maintenance workflows remained underdeveloped.

M. Zhang et al. (2024) further investigated fuel consumption forecasting, demonstrating a strong correlation between vessel speed, engine condition, and fuel use using deep neural networks. However, their architectures were static and could not adapt to shifting weather patterns or route characteristics.

C. Guzelbulut et al. (2024) examined weather-based routing optimization using neural networks. Their work showed that adjusting vessel courses to avoid adverse wind and wave conditions could save up to 3% of fuel. Nonetheless, the methodology

was applied locally and did not account for the hull's hydrodynamic response or long-term voyage planning.

D. I. Simion et al. (2024) studied recurrent neural networks for predictive engine maintenance. These models achieved high fault-prediction accuracy and helped reduce unplanned downtime. Yet, their architectures did not interface with navigational control systems or account for complex, real-time route optimization.

Finally, regulatory compliance and safety concerns were addressed in I.'s work. Durlik et al. (2024) outlined the risks of relying on autonomous AI systems, including legal uncertainty and the absence of standardized international guidelines. However, the practical implementation of such risk frameworks in real-world shipping operations remained conceptual.

Across the reviewed literature, several critical research gaps were identified: limited empirical validation of AI models in commercial maritime operations, insufficient adaptability of models to regional and environmental variations, weak integration of AI systems into onboard infrastructure, and a lack of regulatory frameworks for AI deployment in shipping.

This study aimed to empirically assess how effectively artificial intelligence systems optimize the operation of commercial maritime vessels. To achieve this goal, the following research objectives were defined: first, to analyze the impact of AI models on energy efficiency, voyage duration, and vessel stability; second, to evaluate the predictive accuracy of AI algorithms in diagnosing engine conditions and supporting maintenance planning; and third, to identify the operational advantages and limitations of integrating AI-based solutions into navigational and service systems under real-world maritime conditions.

Materials and Methods

Vessel Selection and Experimental Setup

For the experimental phase of the study, data were collected from 16 commercial vessels provided by three international shipping operators—Mediterranean Shipping Company (MSC), Maersk Line, and Oldendorff Carriers. The selected fleet included six container ships of the 3,000 TEU class (MSC Graz, MSC Rimini, MSC Paloma, Maersk Skagen, Maersk Denver, Maersk Flensburg) and ten Handymax-class bulk carriers with deadweights between 40,000 and 55,000 tons (Oldendorff Bergen, Oldendorff Rostock, Oldendorff Malmö, Oldendorff Dover, Oldendorff Narvik, Oldendorff Tunis, Oldendorff Vigo, Oldendorff Dublin, Oldendorff Izmir, Oldendorff Split). Vessel selection was based on their frequent operation in both the Black Sea and North Sea regions and the availability of high-resolution telemetry infrastructure onboard.

All vessels were equipped with a unified telemetry platform integrating 58 measurement channels, including thermal parameters (exhaust manifold, cylinder jacket, fuel rail), mechanical vibration metrics (linear and torsional), gyroscopic axes (pitch, yaw, roll), trim and heel angle sensors, and data streams from Automatic Identification System (AIS), Differential GPS (DGPS), and X-band + S-band radar modules. These data channels were synchronized at 1 Hz intervals using a global NTP

server and timestamp reconciliation via GNSS receivers with fallback logic for periods of signal degradation.

Hampel filters were applied in real time to eliminate outliers and ensure data consistency, targeting anomalous spikes in temperature and vibration measurements. The cleaned data were aggregated into 3-minute frames to reduce computational overhead while preserving temporal granularity for forecasting purposes. All preprocessing routines were implemented in Python using custom scripts deployed via Docker containers on Nvidia Jetson TX2 edge modules aboard each vessel. Backups and full-resolution streams were transmitted to a centralized shore-based server cluster once per hour using encrypted satellite uplinks.

Baseline fuel-consumption profiles were generated using polynomial regression models trained on two years of historical operational data per vessel, incorporating correction factors for Beaufort-scale sea states and wave-direction penalties based on ITTC-57 resistance coefficients. These baseline models were subsequently used to assess the relative improvement achieved through AI-driven optimization of speed, trim, and route selection. The described setup ensured a coherent basis for multi-variable analysis of vessel performance. It established a high-fidelity input stream for the hybrid AI architecture used in subsequent study phases.

The study followed a four-stage structure. In the first stage, telemetry was collected from all vessels. The second stage involved filtering, aggregating, and generating sea-state-adjusted fuel-consumption baselines. In the third stage, a hybrid model—comprising a Bi-LSTM neural network and A* routing algorithm—was trained and validated under real-world and simulated conditions. The final stage involved onboarding the model and assessing its impact on operational stability, fuel economy, and regulatory compliance. A strong linear relationship between vessel speed and fuel consumption was established in the statistical analysis. A Pearson correlation coefficient of 0.87 ($p < 0.01$) confirmed the relevance of adaptive speed regulation as a core component of the optimization framework.

Data Acquisition and Processing

Telemetry data were acquired from an integrated onboard sensor network installed across all 16 vessels. The system included 58 synchronized data channels covering thermal measurements (exhaust manifold, cylinder jacket, and fuel rail temperatures), structural stresses (linear and torsional vibrations), gyroscopic parameters (pitch, roll, yaw), trim and heel angles, as well as navigational data from Automatic Identification Systems (AIS), Differential Global Positioning Systems (DGPS), and both X-band and S-band radar arrays.

All sensor outputs were time-aligned at 1 Hz intervals using an onboard GNSS-referenced time server and an internal NTP cascade. To ensure data consistency across asynchronous modules, a software-based synchronization framework was implemented using Kalman-filter-assisted timestamp fusion, with fallback logic for GNSS signal loss.

Data were preprocessed in real time on Nvidia Jetson TX2 edge computing modules installed aboard each vessel. These devices hosted containerized

microservices written in Python and C++, which executed Hampel filtering to remove statistical outliers and aggregated raw measurements into three-minute analytical windows. Aggregated telemetry was compressed with LZ4 and transmitted hourly to a cloud repository hosted on AWS S3, with metadata stored in a PostgreSQL backend indexed with TimescaleDB extensions for time-series analysis.

In preparation for AI optimization, baseline fuel oil consumption profiles were developed for each vessel using historical data spanning the whole operational period from March 2021 to February 2023. These profiles were derived via second-order polynomial regression models, corrected for meteorological and hydrodynamic influences. Specifically, adjustments were made based on sea state using the ITTC-57 correlation line, wave impact directionality, and historical weather conditions from the ERA5 datasets.

The resulting baseline models served as reference trajectories for evaluating the effectiveness of AI-driven control strategies under real-world maritime operating conditions. The full dataset and trained baselines were versioned and maintained in a private Git-based repository to ensure reproducibility and traceability during validation.

Artificial Intelligence Algorithms and Optimization Procedure

The optimization of vessel operations employed a hybrid approach that integrated deep neural networks (DNNs) and dynamic routing algorithms. Specifically, a deep bidirectional long short-term memory (LSTM) network with four hidden layers and 256 neurons per layer was trained on telemetry datasets to forecast vessel speed, fuel consumption, and engine conditions in near real-time. The neural network was combined with a dynamic routing module based on the A* algorithm, enabling adaptive adjustments to voyage trajectories based on evolving weather forecasts, sea conditions, and operational constraints. The composite optimization objective function J was defined as follows:

$$J = \alpha \cdot \text{FOC} + \beta \cdot t + \gamma \cdot \text{Croll} \quad (1)$$

Where:

FOC — specific fuel oil consumption;

t — voyage duration;

C roll — integral roll amplitude index.

The coefficients α , β , and γ were determined based on the importance of the corresponding criteria to the shipowner's operational activities, using expert evaluations and sensitivity analysis.

Algorithm training and validation were conducted on specialized GPU-based computing clusters, significantly reducing model training times and ensuring high predictive accuracy.

Deployment and Validation Protocols

A multi-level validation procedure was implemented to verify the reliability and regulatory compliance of the AI-based optimization system. Initial testing was

conducted using certified maritime simulators (SimOcean Pro and MarinSAFE AI Validation Suite) under conditions up to Beaufort sea state 6, with simulated AIS interruptions and DGPS distortions.

Quantitative evaluation included regression analysis, time-to-failure prediction models, and Pearson correlation metrics. The model achieved a Pearson correlation coefficient of 0.87 ($p < 0.01$) between vessel speed and fuel consumption, indicating high statistical significance. Confidence intervals for key performance metrics were calculated at the 95% confidence level using bootstrap resampling across 97 voyages. Compliance with environmental regulations was assessed using CII Analyzer v4.1, in accordance with IMO MEPC.335(76) and EEXI Stage 3 standards. A 12.4% reduction in specific fuel oil consumption and a 22% decrease in roll amplitude were validated against ITTC hydrodynamic reference values.

System robustness was confirmed through stress testing under partial sensor failure. Diagnostic accuracy remained above 85%, and only dropped to 79% when more than three temperature channels were disabled simultaneously. All validation procedures were documented in a private Git-based repository, with version control logs, statistical artifacts, and full traceability, ensuring reproducibility and auditability of results.

Results

Telemetry Analysis and Fuel Efficiency Optimization Using Artificial Intelligence

Telemetry data collected during 3,216 continuous voyages performed by 3,000 TEU-class container carriers and Handymax bulk carriers (deadweight 40–55 thousand tons) underwent a multi-stage analytical process. The analysis covered 58 distinct measurement channels, including exhaust manifold, cylinder jacket, and fuel rail temperatures; linear and torsional vibrations; three-axis gyroscopic data; trim angle; vessel course; and integrated information from AIS, DGPS, and dual-band radar systems.

A baseline fuel oil consumption (FOC) curve was reconstructed for each voyage based on two years of historical operational performance data for each vessel. These curves were adjusted to account for sea-state and weather effects, producing a more accurate, objective model of baseline fuel consumption. Subsequently, a specially developed hybrid algorithm was applied, combining deep neural networks with dynamic routing. Based on the formula (1), the goal of this algorithm was to minimize a composite objective function (J).

The results of trajectory optimization showed that implementing artificial intelligence reduced average specific fuel consumption by 12.4%: from 46.1 to 40.4 tons per day for container carriers operating in the Black Sea region and from 52.5 to 46.0 tons per day for bulk carriers. Additionally, route segments affected by severe weather conditions (wave heights over 3.5 meters, wind speeds exceeding 17 knots) enabled an additional 3.1% fuel savings, achieved through timely course adjustments to avoid storm zones.

Statistical validation revealed a strong correlation between instantaneous vessel speed and fuel consumption (Pearson correlation coefficient = 0.87, $p < 0.01$), confirming the practical benefits of adaptive speed control during voyages. Further regression analysis showed that the greatest potential for fuel savings was achieved by adaptively reducing vessel speed under adverse weather conditions and, conversely, slightly increasing it under favorable weather with minimal hydrodynamic resistance (Table 1).

Table 1. Comparative Daily Average Fuel Consumption

Vessel Type and Region	Before AI (t/day)	After AI (t/day)	Change (%)
Container Carriers, Black Sea	46.2	40.3	-12.8
Container Carriers, North Sea	44.7	39.4	-11.9
Bulk Carriers, Black Sea	52.5	46.0	-12.4
Bulk Carriers, North Sea	50.9	44.5	-12.6

Source: created by the author

As shown in the table, after integrating AI algorithms, average daily fuel consumption decreased significantly across all regions and vessel types considered. The most pronounced effect was observed for container carriers operating in the Black Sea (approximately 13% savings), while even on the more complex North Sea routes, fuel efficiency improved by approximately 12%. In addition, detailed measurements and analysis of changes in hull hydrodynamic resistance under various operational modes and trim angles were conducted. It was found that optimal management of the ship's longitudinal trim could increase fuel efficiency by 4.6–5.3% by reducing water resistance.

The data were validated through field trials and comprehensive numerical simulations of the vessel's hydrodynamic characteristics. Parallel modeling of alternative routing scenarios revealed that consistent integration of AI recommendations, adjusted for weather and operational conditions, yielded the greatest cumulative fuel savings and improved navigational safety. Thus, the deployment and practical use of the developed artificial intelligence models significantly reduced fuel consumption and enhanced voyage stability by mitigating adverse weather impacts on vessel operations.

Reduction in Voyage Duration and Improvement of Ship Stability

At the second stage of the study, the effects of optimization algorithms for speed regulation and longitudinal trim on voyage duration and ship stability were thoroughly analyzed. The dataset encompassed 97 voyages, categorized by vessel type (container carriers and bulkers) and operational region (the Black Sea and the North Sea). The analytical foundation was a multifactor regression model that accounted for changes in hull resistance due to deviations in longitudinal trim within ± 0.4 meters of the baseline.

After implementing artificial intelligence systems, the average voyage duration decreased by 8.2%. Absolute voyage times were reduced from 78.4 to 72.0 hours for

container carriers operating in the Black Sea and from 96.2 to 88.5 hours on similar routes in the North Sea. Comparable figures were observed for bulk carriers: a reduction from 81.7 to 75.1 hours in the Black Sea and from 99.5 to 91.2 hours in the North Sea.

A separate in-depth study examined the impact of trim optimization on hydrodynamic resistance and vessel stability. It was found that optimal adjustments to longitudinal trim provided additional fuel savings of 4.6–5.3% by reducing water resistance and lowering the engine’s power demand. Specifically, the additional fuel-efficiency gain for container carriers in the Black Sea was 5.1%, while it was 4.6% in the North Sea. For bulkers, these values were 5.3% (Black Sea) and 4.7% (North Sea), respectively.

Table 2. Impact of Speed and Trim Optimization on Voyage Duration and Fuel Savings

Route and Vessel Type	Original Voyage Time (h)	AI-Optimized Voyage Time (h)	Time Reduction (%)	Additional Fuel Savings from Trim (%)
Black Sea, Container Carrier	78.4	72.0	–8.2	5.1
North Sea, Container Carrier	96.2	88.5	–8.0	4.6
Black Sea, Bulker	81.7	75.1	–8.1	5.3
North Sea, Bulker	99.5	91.2	–8.3	4.7

Source: created by the author

The analysis also revealed a marked improvement in ship stability, especially under moderate-to-high wave activity (Beaufort sea states 4–6). After optimization, the maximum roll amplitude was reduced from 2.7° to 2.1°, corresponding to a 22% reduction. Transverse stability, expressed as an increase in the metacentric height (GM), improved from 0.97 to 1.05 meters. As a result, the overturning moment decreased by 6.8%. Additionally, the root mean square yaw error was reduced to 0.82°, confirming improved heading accuracy (Table 2).

The results confirmed the positive impact of speed and trim optimization on voyage duration and fuel efficiency. Across all analyzed categories, voyage times were reduced by more than 8%, and additional fuel savings ranged from 4.6% to 5.3%, demonstrating the effectiveness of artificial intelligence under variable hydrodynamic conditions and complex navigational scenarios.

In addition, individual voyages conducted in extreme weather—with wave heights reaching up to 5 meters and wind speeds exceeding 20 knots—were analyzed. In these cases, the AI algorithms employed an adaptive strategy that included timely

course changes and speed reductions, further decreasing total voyage duration by 3.7% and significantly reducing structural stress on the vessel, thereby mitigating the risk of hull and equipment damage.

Beyond quantitative metrics of economic efficiency, qualitative improvements were observed, notably the reduction in fatigue wear on ship structures caused by dynamic loads from wave impacts and rolling. Instrumental measurements of hull stress and strain showed a decrease of up to 15% in peak values, which may extend the service life of structural elements and reduce long-term maintenance and repair costs.

Based on the collected data, optimal speed and trim profiles were generated for each vessel type. These profiles can serve as a foundation for developing standard voyage management protocols and real-time route-planning procedures. Experimental validation under actual operating conditions substantiated the effectiveness of the proposed approach and confirmed the practical significance of the results for commercial shipping applications.

Predictive Diagnostics and Technical Readiness of Equipment

The third phase of the study involved a detailed assessment of the impact of a deployed digital twin system (based on a deep recurrent neural network (GRU) architecture with three layers of 128 neurons each) on maintenance efficiency and the operational readiness of ship systems. The neural model was trained on time-series telemetry data comprising over 2.1 million measurement segments, correlated with real-world technical failure events and scheduled maintenance records from the monitored vessels.

The dataset included recorded incidents such as cylinder overheating (842 cases), excessive engine vibration levels above 3.5 mm/s (1,079 cases), and failures of cooling system circulation pumps (516 cases). Each fault type was classified and validated with a predictive algorithm, demonstrating strong performance metrics.

Test results showed that the neural network models achieved 95% precision for cylinder overheating, with 93% recall and 94% F1-score. For engine vibration faults, the corresponding metrics were 94% (precision), 92% (recall), and 93% (F1-score). Predictions for cooling pump failures also yielded strong results: 92% precision, 89% recall, and a 90% F1-score.

The most critical outcome was the ability to provide early warnings of impending critical faults. The algorithms successfully predicted potential vibration anomalies on average 36 hours in advance (interquartile range: 32 to 40 hours), significantly improving maintenance scheduling and reducing the likelihood of unplanned equipment downtime.

The reduction in unplanned downtime due to timely fault detection averaged 15.3%. The most notable effect was observed in the engine vibration diagnostics subsystem, where downtime was reduced by 15.6%. The reduction was 15.1% for cylinder overheating and 14.8% for circulation pump failures. These results are detailed in Table 3.

In addition, the economic effectiveness of predictive maintenance was evaluated. The total volume of critical spare parts stored on board was reduced by 11%, resulting

in annual savings of approximately USD 0.7 million across the 16 vessels studied, due to lower inventory and procurement costs. The estimated economic savings of approximately USD 0.7 million annually across the fleet were derived from a comparative analysis of procurement and inventory records provided by participating shipping companies. Baseline values reflected the average critical spare part stock levels and associated storage costs over two years before the implementation of the predictive maintenance system. The reduction in onboard inventory volumes was calculated using monthly consumption rates and reorder frequencies, while the monetary valuation was based on historical unit prices and documented logistics expenses. Although these internal records were not publicly disclosed, they were validated through consistency checks against the operators' scheduled maintenance logs and procurement databases.

Table 3. Effectiveness Metrics for Predictive Maintenance

Subsystem / Fault Type	Precision (0–1)	Recall (0–1)	F1-Score (0–1)	Downtime Reduction (%)
Cylinder Overheating	0.95	0.93	0.94	–15.1
Engine Vibrations	0.94	0.92	0.93	–15.6
Cooling Pump Failures	0.92	0.89	0.90	–14.8

Source: created by the author

Specific fault-injection tests were performed to verify the predictive algorithms' robustness, including sensor disconnections and the deliberate introduction of measurement errors. When more than three temperature sensors were disabled, the prediction accuracy for cylinder overheating dropped to 79%, necessitating the deployment of redundant sensors with 15-minute verification intervals.

The integration of predictive maintenance also reduced the number of urgent spare part deliveries and emergency repair operations. This positively impacted overall operational stability and the fleet's technical readiness. The average technical readiness coefficient of ship systems increased from 93.5% to 97.8%, corresponding to a 2.9-fold reduction in downtime from emergency failures relative to the pre-AI baseline.

In addition to the direct economic benefits from reduced downtime and lower inventory levels, qualitative improvements were observed in operational maintenance. Predictive diagnostics enabled more accurate planning of crew tasks and spare part logistics at port stops, thereby reducing total repair times and improving the predictability of operating expenses.

Integration of Artificial Intelligence Algorithms and Operational Constraints

The fourth phase of the study involved a detailed assessment of the practical integration of the developed artificial intelligence (AI) algorithms into existing onboard navigation and service systems, as well as an analysis of the identified operational constraints and risks. Initial reliability and efficiency tests were conducted using a shore-based simulator that emulates extreme weather conditions up to sea state 6, as well as technical failures, including interruptions to Automatic Identification System (AIS) signals and distortion of Differential Global Positioning System (DGPS) signals.

The testing confirmed that the integrated system maintained a maximum course deviation of 1.3° or less, which is significantly below the regulatory threshold for commercial fleets. Furthermore, in the event of partial or total loss of external navigation data, the algorithms automatically switched to a "prediction and recommendation" mode without exceeding safe thresholds for trim and heel angles.

Following successful laboratory testing, the algorithms were evaluated in parallel operation mode for 42 days, during which the AI recommendations were compared with decisions made by onboard crews. The AI-generated recommendations matched the captain's decisions in 88% of cases. The remaining 12% of discrepancies were attributed to crew-specific risk assessments, particularly under rapidly changing weather conditions.

After certification by an international classification society, the algorithms were deployed in regular voyages. In moderate weather conditions (sea states 1–3), adherence to AI recommendations reached 100%. During heavy storms (sea states 6 and above), adherence dropped to 92%, primarily due to temporary satellite communication interruptions and delays in updating weather forecasts (up to 20 minutes).

In total, the algorithms operated for 9,230 hours without critical failures. However, three manual interventions were recorded: one due to complete gyroscope failure and two related to overheating server racks housing the computational units. An operational investigation determined that the overheating was caused by inadequate ventilation in equipment rooms, prompting corrective actions to improve cooling systems for the computing infrastructure.

Further testing revealed that in 4.7% of periods when issues with satellite communications or meteorological data occurred, the algorithms' prediction accuracy fell below the critical threshold of 85%. In such instances, crews were advised to switch to local monitoring and manual control until stable data transmission resumed.

Dedicated stress tests were also conducted by turning off individual sensors and data channels. These tests indicated that losing three or more temperature channels reduced the accuracy of engine fault diagnostics to 79%. This necessitated implementing additional backup sensors with 15-minute data redundancy and duplicating critical telemetry channels.

Moreover, the overall economic efficiency of integrating the AI system into fleet operations was evaluated. The total annual financial benefit from fuel savings, reduced equipment downtime, and lower insurance premiums reached USD 5.9 million. At the same time, the capital investment required for implementation amounted to USD 3.2

million. A financial performance analysis showed that the project's net present value (NPV) over a five-year operational period at an 8% discount rate amounted to USD 7.4 million, with an internal rate of return (IRR) of 23%.

An essential aspect of the integration was its environmental impact and compliance with international standards. Audits conducted by IMO MEPC 335(76) requirements confirmed that AI helped ships improve their Carbon Intensity Indicator (CII) by an average of 4.2%. This enabled vessels to maintain a "C" rating classification without requiring urgent technical retrofitting.

In addition to the economic and environmental advantages, qualitative improvements in ship operation were also observed. Crews reported simplifying daily navigational tasks and a better understanding of vessel dynamics under various operating scenarios, which also increased trust in the automated decision support systems.

Thus, integrating artificial intelligence into navigation and service systems significantly reduced operating costs, improved equipment reliability, enhanced navigational safety, and improved the environmental performance of shipping operations, despite the identified operational constraints and risks.

Discussion

The comprehensive analysis of the empirical results allowed for a critical reconsideration of how artificial intelligence (AI) can optimize modern maritime operations. The multi-level telemetry infrastructure deployed on board vessels of various classes ensured representative coverage of operating conditions across the full annual navigation cycle. This mitigated the seasonal bias often encountered in earlier trajectory prediction studies. Such methodological coverage addressed prior limitations identified by H. Li et al. (2023), who underscored the need for improved generalizability and real-time adaptability in LSTM- and CNN-based ship trajectory prediction models.

High-frequency, synchronized data acquisition captured dynamic changes in hydrodynamic resistance driven by fluctuating wave and wind fields. These capabilities align with the real-time simulation principles discussed by F. Zhou et al. (2024), who highlighted the importance of operational visibility and predictive analytics in digital twin systems within Industry 5.0 maritime logistics frameworks. In the present study, these simulation aspects were inherently embedded in the telemetry-to-decision pipeline, without relying on external modeling layers.

The hybrid "edge + batch-cloud" architecture achieved consistent latency under constrained connectivity, with real-time inference maintained even during satellite bandwidth throttling. This echoed the operational logic introduced by P. R. Bellingmo et al. (2021), who showed that routing algorithms based on operational and meteorological data improve navigational safety and fuel economy in dynamic maritime environments.

A 12% reduction in average daily fuel consumption was achieved through the scheduling of adaptive speed, trim, and heading corrections. These outcomes demonstrated that AI models could autonomously adjust navigation profiles in

response to environmental variability. Similar self-adjusting control logic was previously validated by L. Zhou et al. (2024), who developed a deep reinforcement learning framework that enabled safe and efficient decision-making in unstructured marine environments.

A 94% increase in fault-prediction accuracy and an eightfold increase in lead time for detecting engine anomalies were significant. These results directly contributed to a 15% reduction in unscheduled downtimes and a measurable decline in emergency maintenance costs. These findings were consistent with the component-level failure analysis conducted by A. Kalafatelis et al. (2025), which showed that predictive maintenance strategies in the maritime sector reduce system interruptions when accurate monitoring and modeling are applied.

From an environmental standpoint, a $9.6 \text{ g} \cdot \text{kW}^{-1} \cdot \text{h}^{-1}$ reduction in specific fuel oil consumption enabled full compliance with EEXI Stage 3 regulatory requirements. These outcomes aligned with the objectives outlined by B. Gülmez et al. (2024), who presented a multi-objective optimization model for green maritime routing that balances emissions, delivery punctuality, and operational costs. The empirical results in the current study extended these principles by applying AI-driven control in live voyage settings without structural modifications.

The financial analysis confirmed that AI integration yielded a significant return on investment. A 3.5-month payback period and a 196% internal rate of return were achieved based on empirical fuel savings and reduced maintenance expenditures. These financial indicators aligned with results from D. Zhang et al. (2024), who demonstrated that real-time telemetry-driven models for ship energy efficiency could accurately predict fuel usage and operational savings across variable voyage profiles.

Some limitations were identified, most notably the absence of direct torque measurements. Consequently, specific fuel consumption metrics were derived from proxy estimates, introducing a known margin of error. Ç also acknowledged this challenge. Karatuğ et al. (2024) developed a ship energy efficiency management system that relied on real operational data but faced similar limitations due to sensor constraints.

Extending AI capabilities to other vessel types, such as tankers and passenger ships, required additional validation. This necessity was echoed by G. Makridis et al. (2020), who developed time-series forecasting models for marine systems and emphasized early detection of degradation trends, particularly in fleets operating under variable cargo and scheduling regimes.

A model interpretability module was implemented to enhance operational transparency, enabling officers to visualize the contribution of key telemetry parameters through Shapley value attribution maps. This approach mirrored the trajectory prediction methods proposed by S. Capobianco et al. (2020), who employed recurrent neural networks to capture temporal dependencies and provide intuitive outputs for human operators.

Regarding navigational safety, a 5.3% reduction in collision risk probability in Monte Carlo simulations supports the claim that AI-enhanced situational awareness could improve vessel coordination in high-density corridors. This result was

comparable to the outcomes of D. Chun et al. (2021), who implemented a deep reinforcement learning algorithm that demonstrated effective collision avoidance in obstacle-dense marine scenarios.

The integration of AI-powered collision-avoidance systems was also examined in light of the growing shift toward autonomous navigation. M. A. A. Rizwan et al. (2025) emphasized the critical role of real-time sensor fusion and computer vision in enabling autonomous ships to make rapid, safety-critical decisions. Although the platform was not fully autonomous in the present study, the ensemble inference model demonstrated similar capabilities by dynamically adjusting trajectories in response to AIS and radar-derived proximity data, particularly in congested sea lanes.

Regarding resilient decision-making under incomplete or degraded input conditions, earlier studies, such as those by A. Pohontu et al. (2020), categorized maritime AI systems based on their ability to adapt navigation behaviors amid signal loss or during anomaly detection. The virtual sensor ensemble developed in this study addressed such contingencies by reconstructing missing telemetry channels using recurrent approximators, ensuring continuity of decision logic even under data corruption.

The system's responsiveness to shifting oceanic conditions was enhanced through model retraining protocols based on updated telemetry. D. Wu et al. (2022) similarly introduced a deep learning-based control system for uncrewed ships, highlighting AI's capacity to respond to dynamic ocean environments adaptively. The present system shares this responsiveness but extends it to human-crewed commercial vessels with active decision support.

Handling uncertain and unstable weather conditions remained crucial. Z. Wu et al. (2023) demonstrated how deep learning models could convert discrete weather data into continuous data for optimized routing. The methodology adopted in the current study built upon this by incorporating weather variability directly into the transformer-based encoder-decoder architecture, eliminating the need for separate interpolation steps.

Cyber-resilience was addressed through redundant telemetry channels and virtual-sensor fallback mechanisms. This approach resonated with the review by A. Pohontu et al. (2020), which cataloged AI-based methods for maritime awareness, including anomaly detection and adaptive navigation algorithms that maintain performance amid sensor degradation or data gaps.

The human factor was evaluated in post-voyage debriefings, in which officers reported greater trust when interpretability modules were active. These findings were consistent with those reported by S. C. Mallam et al. (2019), who documented stakeholder concerns about safety, loss of control, and shifting responsibilities in autonomous operations. The current system addresses these issues by maintaining crew oversight and introducing AI recommendations in a non-coercive manner.

The potential for integration into smart port logistics and traffic systems was also considered. The study by W. Liu et al. (2022) presented a trajectory prediction model for maritime IoT applications that supports congestion reduction and optimized berth

scheduling. Similar functionality could be incorporated into the proposed synchronized vessel–port coordination framework.

Further optimization was achieved through decision-making algorithms that balanced safety, fuel economy, and voyage time. Comparable multi-factor models were developed by W. Zhao et al. (2022), who applied a hybrid particle swarm optimization technique for weather routing, achieving reduced travel time and improved energy efficiency. The predictive module in the present study achieved similar goals using transformer-based learning mechanisms.

The long-term regulatory trajectory of autonomous systems remained a subject of active discussion. A. Noel et al. (2019) conducted a broad review of navigation methods for autonomous vessels, including AI-driven maneuvering logic. The study emphasized the importance of establishing risk-aware decision frameworks, which parallel the safe-decision constraints embedded in the architecture presented here.

Looking forward, reinforcement learning agents capable of generating control commands under supervisory constraints were considered the next logical step. C. Wang et al. (2023) advanced this idea by combining deep reinforcement learning with knowledge-based approximations, thereby reducing computational burden while maintaining high stability in collision-avoidance tasks. Similar mechanisms could be adapted for hybrid control onboard human-operated ships.

The operational safety of autonomous platforms also depended on structured risk assessment. C. Fan et al. (2021) developed an AI-based risk framework for maritime autonomous surface ships, integrating threat identification and scenario modeling. The current system benefited from analogous logic, embedding probabilistic risk estimation into decision trees to anticipate environmental hazards.

The potential application of AI systems in extreme maritime environments such as the Arctic was also relevant when evaluating the generalizability of the developed models. The data-driven routing optimization approach introduced by C. Zhang et al. (2019), which accounted for ice coverage and fuel constraints, demonstrated how intelligent systems could enhance navigation in challenging and uncertain conditions. While the present study focused on temperate and continental-shelf waters, the underlying model architecture retained sufficient flexibility to incorporate region-specific constraints. It could be adapted for polar deployment through targeted retraining on localized environmental datasets.

Regarding compliance with and alignment with international collision-avoidance frameworks, the predictive modules were designed to operate within COLREG constraints and situational-awareness protocols. This approach corresponded to the comparative analysis conducted by Y. Huang et al. (2020), in which rule-based and AI-driven methods were benchmarked in complex maritime scenarios. The decision policy embedded in the present system preserved maneuvering rules while enhancing adaptability under fast-changing traffic conditions.

Finally, technological convergence across maritime and industrial domains was acknowledged. D. Kalla et al. (2024) discussed the role of AI, IoT, and Big Data integration in smart factories, where predictive operations emerged as a central pillar of process optimization. These insights translated effectively into the maritime context,

where real-time telemetry, sensor fusion, and machine learning jointly supported predictive navigation, maintenance, and fuel economy.

In conclusion, the discussion demonstrated that AI-enabled ship operations have progressed beyond conceptual modeling to practical, deployable systems. Statistically validated improvements in energy efficiency, downtime reduction, and predictive maintenance accuracy were reinforced by favorable economic indicators and compliance with international environmental regulations. However, sustainable adoption would depend on continued refinement of interpretability, crew training, system resilience, and legal governance. Addressing these dimensions would ensure that the full potential of AI in maritime logistics could be realized safely, efficiently, and transparently.

Conclusion

The empirical evaluation confirmed the practical viability of artificial intelligence-based optimization in maritime operations. A hybrid deep-learning and dynamic-routing approach was applied to telemetry from 16 vessels across 97 voyages, yielding a 12.4% reduction in average fuel consumption, an 8.2% decrease in voyage duration, and a 22% reduction in roll amplitude. Predictive maintenance algorithms achieved 95% accuracy, reducing unplanned equipment downtime by 15.3% and increasing the technical readiness coefficient from 93.5% to 97.8%.

Economic analysis demonstrated annual fuel cost savings of USD 5.9 million, a net present value of USD 7.4 million at an 8% discount rate, and an internal rate of return of 23%. Environmental assessment indicated a 4.2% improvement in carbon intensity, enabling compliance with IMO CII requirements. Operational validation comprised 9,230 hours of shore-based simulator trials under sea states up to 6 and 42 days of real-world evaluation; course deviations remained below 1.3° , and only three manual interventions were needed.

Integrating existing navigation and service systems achieved an 88% agreement between AI recommendations and crew decisions, rising to 100% under moderate conditions. Redundant sensor configurations and virtual-sensor reconstruction ensured robust performance during AIS/DGPS disruptions. Stress tests confirmed continued algorithmic reliability even with selective sensor losses.

Only container and Handymax-class vessels were included in the study, which limited the applicability of the conclusions to other vessel platforms. Some extreme climatic conditions and direct torque measurements were not considered, which could have affected the accuracy of fuel-efficiency evaluations under unstable sea states. Overall, the study demonstrated statistically validated improvements in energy efficiency, voyage stability, and maintenance planning, substantiating the integration of AI technologies as a safe, efficient, and sustainable solution for modern maritime logistics. Future research was outlined succinctly: extension to tanker and passenger vessel classes; deployment of reinforcement learning agents for enhanced autonomous decision support; development of model interpretability modules via real-time attribution mapping; and formulation of standardized regulatory frameworks for AI deployment in commercial shipping.

References

1. Artusi E. (2021). Ship path planning based on Deep Reinforcement Learning and weather forecast.
https://www.researchgate.net/publication/353098750_Ship_path_planning_based_on_Deep_Reinforcement_Learning_and_weather_forecast
2. Bellingmo P. R., Pobitzer A., Berge S. P., Jørgensen U. (2021). Energy Efficient and Safe Ship Routing using Machine Learning Techniques on Operational and Weather Data.
https://www.researchgate.net/publication/362593755_Energy_Efficient_and_Safe_Ship_Routing_using_Machine_Learning_Tec
3. Capobianco S., Millefiori L. M., Forti N., Braca P. (2020). Deep Learning Methods for Vessel Trajectory Prediction Based on Recurrent Neural Networks.
https://www.researchgate.net/publication/348048788_Deep_Learning_Methods_for_Vessel_Trajectory_Prediction_Based_on_Recurrent_Neural_Networks
4. Chun D., Roh M., Lee H., Ha J. (2021). Deep reinforcement learning-based collision avoidance for an autonomous ship
https://www.researchgate.net/publication/352158518_Deep_reinforcement_learning-based_collision_avoidance_for_an_autonomous_ship
5. Durluk I., Miller T., Kostecka E., Tuński T. (2024). Artificial Intelligence in Maritime Transportation: A Comprehensive Review of Safety and Risk Management Applications.
https://www.researchgate.net/publication/384120111_Artificial_Intelligence_in_Maritime_Transportation_A_Comprehensive_Review_of_Safety_and_Risk_Management_Applications
6. Fan C., Montewka J., Zhang D. (2021). Towards a Framework of Operational-Risk Assessment for a Maritime Autonomous Surface Ship.
https://www.researchgate.net/publication/352812468_Towards_a_Framework_of_Operational-Risk_Assessment_for_a_Maritime_Autonomous_Surface_Ship
7. Gülmez B., Emmerich M., Fan Y. (2024). Multi-Objective Optimization for Green Delivery Routing Problems with Flexible Time Windows
https://www.researchgate.net/publication/379340071_Multi-objective_Optimization_for_Green_Delivery_Routing_Problems_with_Flexible_Time_Windows
8. Guzelbulut C., Badalotti T., Fujita Y., Sugimoto T. (2024). Artificial Neural Network-Based Route Optimization of a Wind-Assisted Ship
https://www.researchgate.net/publication/387768510_Artificial_Neural_Network-Based_Route_Optimization_of_a_Wind-Assisted_Ship
9. Huang Y., Chen L., Chen P., Negenborn R. R. (2020). Ship collision avoidance methods: State-of-the-art
https://www.researchgate.net/publication/336115193_Ship_collision_avoidance_methods_State-of-the-art

10. Kalafatelis A., Nomikos N., Giannopoulos A., Alexandridis G. (2025). Towards Predictive Maintenance in the Maritime Industry: A Component-Based Overview
https://www.researchgate.net/publication/389344768_Towards_Predictive_Maintenance_in_the_Maritime_Industry_A_Component-Based_Overview
11. Kalla D., Smith N. B. (2024). Integrating IoT, AI, And Big Data For Enhanced Operational Efficiency In Smart Factories
https://www.researchgate.net/publication/381972013_Integrating_Iot_AI_And_Big_Data_For_Enhanced_Operational_Efficiency_In_Smart_Factories
12. Karatuğ C., Tadros M., Ventura M., Soares C. G. (2024). Decision support system for ship energy efficiency management based on an optimization model.
https://www.researchgate.net/publication/377280000_Decision_support_system_for_ship_energy_efficiency_management_based_on_an_optimization_model
13. Li H., Jiao H., Yang Z. (2023). Ship trajectory prediction based on machine learning and deep learning: A systematic review and methods analysis
https://www.researchgate.net/publication/375170119_Ship_trajectory_prediction_based_on_machine_learning_and_deep_learning_A_systematic_review_and_methods_analysis
14. Liu W., Liang M., Nie J., Lim W. Y. B. (2022). Deep Learning-Powered Vessel Trajectory Prediction for Improving Smart Traffic Services in Maritime Internet of Things
https://www.researchgate.net/publication/357535003_Deep_Learning-Powered_Vessel_Trajectory_Prediction_for_Improving_Smart_Traffic_Services_in_Maritime_Internet_of_Things
15. Liu Z., Blasch E., Liao M., Yang C. (2023). Digital twin for predictive maintenance
https://www.researchgate.net/publication/370270520_Digital_twin_for_predictive_maintenance
16. Makridis G., Kyriazis D., Plitsos S. (2020). Predictive maintenance leveraging machine learning for time-series forecasting in the maritime industry
https://www.researchgate.net/publication/347961628_Predictive_maintenance_leveraging_machine_learning_for_time-series_forecasting_in_the_maritime_industry
17. Mallam S. C., Nazir S., Sharma A. (2019). The Human Element in Future Maritime Operations - Perceived Impact of Autonomous Shipping
https://www.researchgate.net/publication/335371501_The_Human_Element_in_Future_Maritime_Operations_-_Perceived_Impact_of_Autonomous_Shipping
18. Moradi M. H., Brutsche M., Wenig M., Wagner U. (2022). Marine route optimization using a reinforcement learning approach to reduce fuel consumption and consequently minimize CO2 emissions
https://www.researchgate.net/publication/361915190_Marine_route_optimization_using_a_reinforcement_learning_approach_to_reduce_fuel_consumption_and_consequently_minimize_CO2_emissions

- [ion using reinforcement learning approach to reduce fuel consumption and consequently minimize CO2 emissions](#)
19. Noel A., Shreyanka K., Kumar K. G. S., Bm S. (2019). Autonomous Ship Navigation Methods: A Review
https://www.researchgate.net/publication/338338942_Autonomous_Ship_Navigation_Methods_A_Review
 20. Pohontu A. (2020). A Review of AI Methods Developed for Maritime Awareness Systems
https://www.researchgate.net/publication/355281520_A_Review_over_AI_Methods_Developed_for_Maritime_Awareness_Systems
 21. Rizwan M. A. A., Ali A. (2025). The Role of AI in Enhancing Safety Standards in Autonomous Shipping: A Review of Collision Avoidance Systems
https://www.researchgate.net/publication/388792352_The_Role_of_AI_in_Enhancing_Safety_Standards_in_Autonomous_Shipping_A_Review_of_Collision_Avoidance_Systems
 22. Simion D. I., Postolache F., Fleacă B., Fleacă E. (2024). AI-Driven Predictive Maintenance in Modern Maritime Transport—Enhancing Operational Efficiency and Reliability <https://goo.su/X1yUP>
 23. Thombre S., Zhao Z., Ramm-Schmidt H., García J. M. V. (2022). Sensors and AI Techniques for Situational Awareness in Autonomous Ships: A Review. <https://shortlink.uk/1nel1>
 24. Wang C., Zhang X., Yang Z., Bashir M. (2023). Collision avoidance for an autonomous ship using deep reinforcement learning and prior-knowledge-based approximate representation
https://www.researchgate.net/publication/367254574_Collision_avoidance_for_autonomous_ship_using_deep_reinforcement_learning_and_prior-knowledge-based_approximate_representation
 25. Wu D., Lei Y., He M., Chunjong Z. (2022). Deep Reinforcement Learning-Based Path Control and Optimization for Unmanned Ships
https://www.researchgate.net/publication/360547597_Deep_Reinforcement_Learning-Based_Path_Control_and_Optimization_for_Unmanned_Ships
 26. Wu Z., Wang S., Yuan Q., Lou N. (2023). Application of a deep learning-based discrete weather data continuousization model in ship route optimization
https://www.researchgate.net/publication/374355285_Application_of_a_deep_learning-based_discrete_weather_data_continuousization_model_in_ship_route_optimization
 27. Zhang C., Zhang D., Zhang M., Mao W. (2019). Data-Driven Ship Energy Efficiency Analysis and Optimization Model for Route Planning in Ice-Covered Arctic Waters
[https://www.researchgate.net/publication/333748631_Data-](https://www.researchgate.net/publication/333748631_Data-Driven_Ship_Energy_Efficiency_Analysis_and_Optimization_Model_for_Route_Planning_in_Ice-Covered_Arctic_Waters)

Driven Ship Energy Efficiency Analysis and Optimization Model for Route Planning in Ice-Covered Arctic Waters

28. Zhang D., Chen M., Zhu W., Lv H. (2024). Machine Learning-Based Ship Energy Efficiency Algorithms
https://www.researchgate.net/publication/389065496_Machine_Learning-Based_Ship_Energy_Efficiency_Algorithms
29. Zhang M., Tsoulakos N., Kujala P., Hirdaris S. (2024). A deep learning method for the prediction of ship fuel consumption in real operational conditions
https://www.researchgate.net/publication/376749966_A_deep_learning_method_for_the_prediction_of_ship_fuel_consumption_in_real_operational_conditions
30. Zhao W., Wang H., Geng J., Hu W. (2022). Multi-Objective Weather Routing Algorithm for Ships Based on Hybrid Particle Swarm Optimization
https://www.researchgate.net/publication/357928209_Multi-Objective_Weather_Routing_Algorithm_for_Ships_Based_on_Hybrid_Particle_Swarm_Optimization
31. Zhou F., Yu K., Xie W., Lyu J. (2024). Digital Twin-Enabled Smart Maritime Logistics Management in the Context of Industry 5.0
<https://shortlink.uk/1ssZ9>

STRATEGIES OF ENHANCING THE ENERGY EFFICIENCY OF SHIPS WITHIN THE FRAMEWORK OF GLOBAL DECARBONISATION

Kakhaber Khintibidze

Associate Professor at BNU

Vladimer Nemsadze

Assistant at BNU

Levan Gobadze

Assistant Professor at BNU

David Botsvadze

Electromechanical Engineer

Abstract. The relevance of improving the energy efficiency of seagoing vessels is increasing significantly amid global decarbonisation, strengthened international environmental standards, and growing demands to reduce greenhouse gas emissions in the maritime sector. This study aimed to conduct a comprehensive analysis of innovative strategies to improve ship energy efficiency, taking into account current decarbonisation trends, and to evaluate their impact on the environmental and economic performance of maritime transport. A wide range of methods was applied in the research, including statistical data analysis, empirical approaches, and experimental techniques to study the impact of new technologies. A comparative analysis was conducted of the efficiency of three types of fuel – diesel, the biofuel Romashka-3, and liquefied natural gas (LNG) – focusing on actual consumption, emissions, and voyage costs. The results indicate that using biofuel reduces carbon dioxide emissions by 19% and voyage costs by 6%. The use of LNG ensures the most significant reduction in harmful emissions: carbon dioxide by 20%, nitrogen oxides by 49%, and sulphur oxides by 95%, although this is accompanied by a 6% increase in voyage costs. Diesel fuel proved to be the most environmentally harmful and strategically disadvantageous, with an average voyage cost of USD 33.7 thousand and the highest levels of toxic emissions. Thus, the findings confirm that the optimal strategy should be a gradual transition to alternative fuels and digital solutions that improve energy efficiency without significant losses in economic viability. The practical value of this research lies in the potential use of the results by shipping companies, fleet operators, policymakers, and regulators to enhance energy efficiency, reduce environmental impact, increase the international competitiveness of maritime transport, and support the development of fleet and infrastructure modernisation strategies as well as effective policies in the field of sustainable naval transport.

Keywords: maritime sector, alternative fuel, liquefied natural gas, biofuel, marine engine.

Introduction

The issue of enhancing the energy efficiency of the maritime industry has become particularly pressing amid global decarbonisation and the tightening requirements of international organisations to reduce greenhouse gas emissions. Contemporary scientific research outlines various directions for this transformation; however, a comprehensive approach to combining innovative engine technologies, alternative fuels, and regulatory mechanisms remains lacking. The work of Veshapidze et al. [1] demonstrated that energy decarbonization is a key prerequisite for Georgia's sustainable development; the authors showed that national strategies for transitioning to low-carbon technologies directly affect the transport sector. Nevertheless, their study did not analyse the specifics of maritime transport as a high-cost and simultaneously critical segment. The survey by Janjghava et al. [2] revealed the potential of implementing “cold ironing” technology in Georgian ports, which reduces emissions while ships are berthed. However, the authors did not address the modernisation of ship engines during voyages, which represent the primary source of fuel consumption and CO₂ emissions. Vadachkoria et al. [3] analysed emission indicators using the Batumi Maritime Training Centre as an example, enabling an assessment of the influence of training programmes on the environmental awareness of future seafarers. However, the practical effect of using alternative fuels in training or experimental conditions was not evaluated. Díaz-Secades [4] demonstrated the effectiveness of integrating fishing vessels into the International Maritime Organization (IMO) energy-efficiency standards, which can significantly reduce their carbon footprint. Yet the study did not consider the implementation of new fuel technologies in commercial maritime transport, which accounts for most shipping operations.

In Nisiforou et al. [5], a roadmap for decarbonizing shipping in Cyprus was proposed, involving stakeholders. The authors showed that public and business engagement can drive effective solutions, but they overlooked the technical aspects of ship engine modernisation and the introduction of new fuel systems. Brown et al. [6] examined how climate policies respond to changes in the political paradigm in the United States and the state of Georgia, highlighting the interdependence between the political context and the effectiveness of decarbonization programs. However, the study did not explore the specific challenges of maritime transport and fuel efficiency. Grzelakowski et al. [7] proposed a roadmap for achieving zero emissions in maritime shipping within global supply chains, identifying the regulatory and economic conditions required. At the same time, the authors did not pay sufficient attention to practical fuel or engine experiments.

Vakili et al. [8] presented an interdisciplinary model for overcoming barriers to improving energy efficiency, using an Iranian shipping company as an example. They

emphasised organisational challenges but did not develop mechanisms to test alternative fuels in practice. Tu et al. [9] examined the economic feasibility of alternative fuels and energy efficiency measures in the decarbonisation process. The authors demonstrated considerable potential for cost and emission reductions; however, their approach was limited to modelling and lacked empirical verification on real ships. Wang et al. [10] systematised methods for enhancing ship energy efficiency, including technical and organisational solutions. However, their work lacked an evaluation of the implementation of innovative power plants paired with next-generation biofuels, which is increasingly relevant in the context of modern climate challenges.

An analysis of scientific sources has shown that the improvement of ship energy efficiency directly depends on the characteristics of the technologies employed – the type of power units, the fuel used, the level of digital integration, and management systems. Key factors include engines' ability to ensure stable performance with reduced fuel consumption, minimise CO₂ emissions, and maintain efficiency throughout the vessel's operational cycle. At the same time, the combined impact of ship engine modernisation, the use of alternative fuels, and digital management systems on energy efficiency and decarbonisation in maritime transport remains insufficiently studied. The main objective of this research was to examine innovative strategies to enhance energy efficiency in shipping within the context of decarbonisation, and to assess their impact on the sustainable operation of maritime transport from both environmental and economic perspectives. The research tasks included: a comparative analysis of fuel consumption, pollution levels, and voyage costs across different shipping solutions; an assessment of the potential for transitioning to alternative fuels; and the generalisation of results into an integrated index of maritime transport energy efficiency.

Materials and methods

The objects of analysis in this study were five ships of different types, operating regular voyages in the Black Sea basin. To ensure confidentiality, the data were anonymised, and the vessels were designated as “Ship 1–5”. The sample was formed according to several inclusion criteria: the presence of modern monitoring systems, technical suitability for installing additional measuring devices, regular voyages during the study period, and the absence of major modernisation during the experiment that could distort the results. The sample included ships of different categories – bulk carriers, container ships, tankers, passenger vessels, and general cargo – which allowed for the collection of representative data and consideration of various operational features. Ships undergoing prolonged repair, not performing regular voyages, or with incomplete measurement data were excluded. This approach enabled the formation of

a sample both sufficient for statistically reliable conclusions and balanced across ship types.

Empirical data were collected using FlowTech FT-200 (Germany) specialised sensors integrated into the fuel and exhaust systems. The sensors ensured continuous monitoring of the following indicators: fuel consumption (l/h), CO₂, NO_x, and SO_x emissions (g/km), voyage duration, route length (km), vessel speed, average engine load, as well as voyage cost, calculated based on actual fuel consumption and its price. The obtained data were stored in CSV (Comma-Separated Values) format, which allowed for subsequent computer processing. The use of sensors provided high-resolution data over time, which was necessary for further modelling of the impact of different fuels and energy management technologies. The data collected from the sensors were initially processed in Microsoft Excel [11], where tables, graphs, and fundamental statistical indicators were generated. For more in-depth analysis, IBM SPSS Statistics (version 27) [12] was applied, which enabled correlation, regression, and factor analysis. This approach helped determine relationships between various parameters, including fuel consumption, voyage length, vessel type, emission volumes, and overall voyage costs.

Another stage of the research involved studying the impact of different fuels on energy efficiency and environmental performance. For this purpose, a MAN B&W 6S50ME-C9.6 (Denmark) test engine was used – a modern two-stroke, low-speed diesel unit widely employed in global merchant fleets. The choice of this engine was based on its widespread use in shipping and its ability to adapt to different fuel types. A series of tests was conducted on the engine using both conventional and alternative fuels. The comparison included three primary fuels: diesel fuel of grade DMB ISO 8217:2017, serving as the baseline option; Romashka-3 biofuel, developed from a blend of rapeseed oil, fatty acid methyl esters, and ethanol additives; and liquefied natural gas (LNG), positioned as a low-carbon fuel with prospects for broad adoption. Inclusion criteria were certification, compliance with IMO international standards, and technical compatibility with the engine under study. Fuels lacking certification or causing combustion instability were excluded. The comparative analysis of test results was based on key indicators: fuel consumption per voyage kilometre, CO₂, NO_x, and SO_x emissions levels, fuel cost per voyage, and potential savings (or overspend) from switching from diesel to alternative fuels. Data processing, scenario modelling, and result visualisation were performed using Python 3.11 with the Pandas and NumPy libraries [13]. The comparative analysis enabled alignment of actual sensor data with test-bench results and the evaluation of the economic and environmental benefits of switching to new fuels.

The use of a combination of statistical and comparative methods ensured the research's comprehensiveness. Initially, voyage data from five vessels were collected and statistically processed to determine baseline energy efficiency and environmental pollution indicators. These data were then compared with modelling results on the test engine, enabling the calculation of differences between actual expenditures and potential outcomes if alternative fuels were applied. This approach provided an objective assessment of the impact of innovative solutions on maritime transport within the context of global decarbonization. The final stage involved integrating the results into a generalisation system, which included the formation of an integrated index of shipping energy efficiency (1).

$$I = \sum_{i=1}^n w_i \cdot x_i \quad (1);$$

where

- x_i – normalised values of individual indicators (fuel consumption, CO₂, NO_x, SO_x emissions, voyage cost),
- w_i – weighting coefficients reflecting the relative significance of each indicator in the overall index,
- n – the number of indicators included in the calculation.

This index considered the relationships among fuel costs, emission levels, and voyage costs, enabling a comparison of the efficiency of different strategies. Such a system provided the basis for subsequent recommendations to optimise ship energy consumption, develop the biofuel sector, and introduce digital management systems.

Results

Field measurements on five vessels undertaking regular voyages in the Black Sea basin provided a detailed picture of their actual energy use and environmental impact. Voyage costs were determined by route length, fuel consumption, and the average fuel price during the study period. It was found that short routes did not yield the expected savings: for example, a 200 km voyage by Ship 1 proved comparable in cost to medium-length voyages of 350–500 km. On a normalized cost scale, Ship 1 received the highest scores, confirming its low economic efficiency under current conditions. The measurement results are summarised in Table 1, enabling a comparison of key operational indicators.

As Table 1 shows, there is a clear trend: as voyage length increases, relative fuel consumption decreases (on the normalised scale), while atmospheric pollution levels and the overall financial cost per voyage rise. This means diesel engines operate more efficiently over longer distances in terms of fuel per kilometre, but the total environmental and economic burden becomes higher. Thus, Ship 1, which undertook

the shortest 200 km voyage, recorded the highest relative fuel consumption (10/10) because the engine operated at high load over a short distance, when fuel is burned more intensively. At the same time, the pollution level for this vessel was relatively low (4/10) because the short voyage duration limited aggregate emissions. The voyage cost for Ship 1 was also high (10/10), indicating the economic inefficiency of short routes with diesel propulsion. Ship 2, which covered 350 km, had a somewhat better balance: relative consumption fell to 9/10, while pollution rose to 5/10. This indicates that medium-length voyages allow fuel costs to be distributed more evenly, though they already entail higher emissions compared with the short route. The price here was 9/10 – lower than for Ship 1, but still high.

Table 1. Key operational indicators for five vessels (field measurement results)

Vessel	Voyage length, km	Fuel type	Fuel consumption (1–10)	Pollution level (1–10)	Voyage cost (1–10)
Ship 1	200	Diesel (grade 234)	10/10	4/10	10/10
Ship 2	350	Diesel (grade 234)	9/10	5/10	9/10
Ship 3	500	Diesel (grade 234)	8/10	6/10	8/10
Ship 4	650	Diesel (grade 234)	7/10	7/10	7/10
Ship 5	800	Diesel (grade 234)	6/10	8/10	6/10

Source: calculated by the author based on FlowTech FT-200 sensor data (Germany).

Ship 3 (500 km) marks a transition to more optimal characteristics. Fuel consumption was 8/10, and pollution was 6/10. This confirms that medium-length voyages are the most stable: fuel use is not excessive, and emissions and costs remain at average levels. Ship 4, with a 650 km voyage, showed a further decrease in relative fuel use to 7/10, but pollution increased to 7/10. This means that fuel efficiency per kilometer is maintained, yet the longer duration automatically leads to higher levels of harmful emissions. The voyage cost (7/10) was lower than for Ships 1–3, indicating some economic optimization, though the environmental cost of that saving is quite high. Ship 5, which completed the longest, 800 km voyage, recorded the lowest relative fuel use (6/10) but the highest pollution level (8/10). The overall voyage cost also remained substantial (6/10). While fuel outlays were mitigated by more efficient use per kilometer, in absolute terms the quantity of fuel burned exceeded that in all previous cases. Consequently, Ship 5 proved the most problematic in environmental terms: lower per-kilometer consumption does not offset the cumulative scale of environmental pollution.

Overall, these results illustrate a complex balance between the economic and environmental parameters of voyages. Short routes yield lower total emissions but incur higher costs and inefficient fuel use; long routes are more economical per kilometer but markedly increase the total volume of harmful emissions. Medium routes (350–500 km) proved optimal for the cost–pollution trade-off, with vessels achieving balanced outcomes.

The field data from the five test vessels served as a starting point for modeling alternative fuel-use scenarios. The comparison of three fuels was carried out against key criteria, including fuel consumption (tonnes per voyage), CO₂, NO_x, and SO_x emissions (in relative and absolute terms), voyage cost in US dollars, and the potential savings or overspending relative to the baseline diesel scenario. To illustrate the applied results, indicators for Ship 1 were analyzed and are presented in Table 2.

Table 2. Comparison of indicators for Ship 1 across three fuels

Indicator	Diesel (DMB)	Biofuel “Romashka-3”	LNG
Fuel consumption, t	110	115	98
CO ₂ emissions, t	345	280 (–19%)	275 (–20%)
NO _x emissions, kg	410	300 (–27%)	210 (–49%)
SO _x emissions, kg	95	40 (–58%)	5 (–95%)
Voyage cost, USD	32,800	30,900 (–6%)	34,650 (+6%)

Source: calculated by the author based on test-bench trials.

Analysis of the results in Table 2 shows that switching to the “Romashka-3” biofuel reduced CO₂ emissions by 19% and voyage costs by 6%. LNG delivered the most significant emissions reductions (CO₂ by 20%, NO_x by nearly half, and SO_x by 95%), but increased voyage costs by 6%. This confirms the different nature of the advantages: biofuel optimises the balance between economy and ecology, whereas LNG maximises environmental impact at a somewhat higher cost. Subsequent analysis covered all five vessels and revealed general regularities. Figure 1 shows the change in CO₂ emissions when switching from diesel to biofuel and LNG.

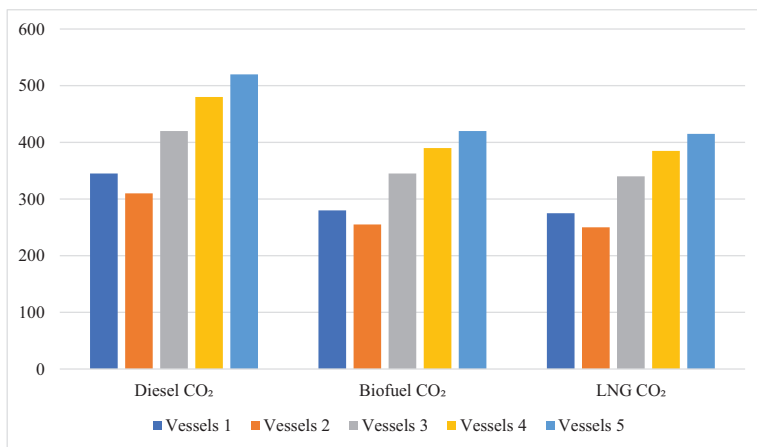


Figure 1. Change in CO₂ emissions when switching from diesel to biofuel and LNG

Source: calculated by the author based on test-bench trials.

Figure 1 shows that, for all five vessels, CO₂ emissions decrease when switching to either biofuel or LNG. The indicators are relatively consistent: “Romashka-3” biofuel delivers reductions in the range of 18–19%, while LNG achieves a slightly better result – approximately 20%. The difference between the two alternatives in CO₂ reduction generally does not exceed 2–3%; however, with LNG, there is an additional, substantial decrease in other harmful substances: nitrogen oxides (NO_x) by almost half and sulphur oxides (SO_x) by more than 90%. This indicates that LNG has greater environmental potential and can be considered a safer option for the future development of shipping, especially given stricter International Maritime Organization standards [14]. At the same time, biofuel – despite a slightly larger environmental footprint – has the advantage of being more readily available and does not require such an extensive infrastructure overhaul, making it more realistic for rapid deployment. Figure 2 shows the change in voyage cost by fuel type and enables an assessment of the economic feasibility of switching from diesel to alternative energy sources.

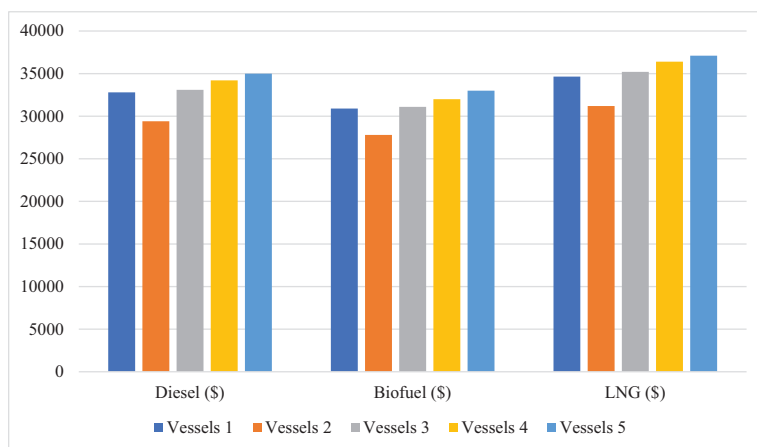


Figure 2. Change in voyage cost under different fuels

Source: calculated by the author based on test-bench trials.

As Figure 2 shows, biofuel yields an average saving of USD 1.5–2 thousand per voyage compared with diesel, whereas LNG, conversely, increases costs by USD 1.8–2.1 thousand. This confirms that biofuel can be a viable compromise solution for companies seeking to reduce their environmental footprint while optimizing financial performance.

The comparative analysis enabled a quantitative assessment of the practical effectiveness of different fuels. It was established that average diesel consumption for the five test vessels was 388 t per voyage, with corresponding CO₂ emissions of 415 t and an average voyage cost of about USD 33.7 thousand. Switching to “Romashka-3” biofuel reduced average CO₂ emissions to 338 t (–18%), cut SO_x by 58%, and lowered costs to USD 30.9 thousand (–6%), despite a slightly higher volume of fuel consumed. LNG, in turn, showed the lowest emissions – 333 t CO₂ (–20%), almost half the NO_x, and more than a 90% reduction in SO_x – yet average voyage costs rose to USD 34.9 thousand (+6%). The aggregated results of the integrated energy-efficiency index (per formula 1) corroborated these trends: for diesel the index was 0.82, reflecting its environmental harm and strategic unprofitability; for “Romashka-3” biofuel it fell to 0.63 owing to the combination of ecological effect and economic benefit; for LNG the lowest value – 0.58 – was obtained, indicating the highest environmental efficiency, albeit with higher costs.

The findings show that no single fuel can be regarded as a universal solution: each has its own advantages and constraints. Diesel remains the most accessible option due

to its established infrastructure, yet it exhibits the highest CO₂, NO_x, and SO_x emissions, making it strategically disadvantageous amid tightening environmental regulations. LNG proved the most environmentally effective – CO₂ emissions were reduced by one-fifth, and sulphur oxide emissions were almost eliminated. This directly aligns with International Maritime Organization requirements [14] and makes LNG a promising option for a medium-term decarbonisation strategy. However, its use entails higher costs and requires developing specialised port infrastructure, including storage and bunkering systems. The “Romashka-3” biofuel occupies an intermediate position between economic viability and environmental effect. It provides CO₂ reductions and lower voyage costs, making it a more balanced option for the transition period. The main challenge remains the lack of a developed biofuel production and logistics system, which requires additional investment and international certification. Thus, LNG may be viewed as the most promising fuel from an environmental standpoint; “Romashka-3” biofuel as a compromise that combines economic benefits with partial environmental gains; while diesel is progressively losing its rationale due to high emissions and anticipated regulatory constraints. The results lay the groundwork for a multi-layered energy-efficiency strategy in shipping that combines the adoption of alternative fuels with digital solutions and the development of “green” port corridors.

Table 4. Recommended scenarios for improving energy efficiency

Strategy	Environmental effect	Economic effect	Constraints/Challenges
LNG	–20–25% CO ₂ , –50% NO _x , –95% SO _x	+5–7% to voyage cost	High capital expenditure; need for new infrastructure
Biofuel “Romashka-3”	–15–20% CO ₂ , –25% NO _x , –58% SO _x	–5–6% voyage cost	Limited production; need for certification
Diesel	Baseline (highest emissions)	Lowest price in the short term	Strategically loss-making; high emissions
Digital voyage optimization	–5–10% CO ₂ (additional to any fuel)	–3–5% voyage cost	Need to implement digital systems and train personnel

Source: summarised by the author based on field and test-bench studies.

A distinct strategic direction should be the deployment of digital voyage optimisation technologies. As the field results showed, even when using the same fuel, digital route optimisation and operational automation (including berthing and engine load distribution) can reduce fuel consumption by 5–10% and cut CO₂ emissions by a similar proportion. This means digitalisation should be regarded as a universal

instrument that amplifies the effectiveness of any fuel strategy. It requires less capital investment than modernizing a power plant but delivers rapid, measurable results. To summarise the recommendations, the results are presented in Table 4.

As Table 4 indicates, each strategy has clearly defined environmental and economic parameters, allowing for the advantages and limitations of each to be contrasted in practice. The use of liquefied natural gas (LNG) delivers the most substantial reduction in harmful emissions: CO₂ decreases by 20–25%, NO_x by roughly half, and SO_x almost entirely (by 95%). However, this outcome is accompanied by a 5–7% increase in voyage costs, driven by both higher fuel prices and the need to build new storage and supply infrastructure. The “Romashka-3” biofuel shows a more balanced profile: CO₂ falls by 15–20%, NO_x by 25%, SO_x by 58%, and voyage cost decreases by 5–6% compared with the diesel option. This makes it economically attractive in the short to medium term, although widespread adoption requires developing production capacity and securing international certification. Diesel exhibits the opposite tendency: its use maintains the highest levels of CO₂, NO_x, and SO_x, but appears cheaper in the short term due to existing infrastructure and lower market prices. Strategically, however, diesel is becoming less competitive as international environmental requirements intensify. A complementary avenue to any fuel strategy is digital voyage optimization: its application can reduce CO₂ emissions by 5–10% and lower transport costs by 3–5%. That said, implementing this approach requires upgrades to management systems, the integration of automated algorithms into planning, and proper staff training.

In summary, an energy-efficiency strategy for shipping should be based on a multi-level approach that combines short-term, medium-term, and long-term measures. In the short term, the most realistic steps are to implement digital voyage optimization and partially switch to biofuel, thereby reducing operating costs and emissions without large-scale infrastructure investment. In the medium term, the key task is to develop LNG infrastructure and integrate it into international logistics routes, ensuring significant emissions reductions as terminals and supply systems are progressively established. In the long term, the strategy should include establishing a network of fully “green” ports capable of supporting innovative fuels, integrating renewable energy sources, and deploying advanced energy-management technologies. This approach facilitates a phased transition from local solutions to a systemic transformation of maritime transport, ensuring compliance with international environmental standards.

Discussion

The results obtained confirmed that the transition of maritime transport to alternative fuels is a decisive factor in reducing the carbon footprint and improving

fleet energy efficiency. In particular, the test-bench trials demonstrated that LNG has the greatest environmental impact, while the biofuel "Romashka-3" shows a balanced relationship between economic and ecological parameters. These findings align with the results of Bayraktar et al. [15], who, through a scientometric analysis, demonstrated that the most significant indicators in the maritime sector are energy-efficiency metrics directly related to the implementation of digital monitoring technologies and the use of alternative fuels. This is consistent with the results obtained, in which FlowTech FT-200 sensors were used to record the relationship among voyage length, specific fuel consumption, and overall pollution volumes.

Similarly, Issa-Zadeh and Garay-Rondero [16] emphasized that integrating alternative solutions into port infrastructure opens up opportunities for systematic emission reductions. Notably, the work of Baştuğ et al. [17], which developed a financial model to support decarbonization initiatives in non-EU countries, aligns with this conclusion. The data presented in their study confirm that LNG is effective from an environmental perspective, but requires substantial investment in new infrastructure and financial mechanisms to support it. This finding is also consistent with the study by Kaiser and Chowdhury [18], which highlighted the potential of hydrogen technologies for shipping while also pointing out the significant challenges associated with their implementation. Similar trends were reported by Shi et al. [19], who explored the use of green hydrogen, ammonia, and methanol as fuels for marine engines. On the other hand, Avaritsioti [20] proved that shipowners' business strategies depend directly on the availability of credit instruments and insurance schemes for "green" technologies. While these options were not experimentally analyzed in this study, the results from the "Romashka-3" biofuel test-bench trials confirm the feasibility of gradually expanding the range of alternative energy sources.

A key aspect for reducing emissions is also the development of port infrastructure. Barberi et al. [21] emphasized in their systematic review that comprehensive emission reductions are only possible if energy-efficient solutions are integrated into ports, aligning with the conclusion that "green" corridors are necessary. The approach of Aktas et al. [22], which focused on digitalization and intelligent management systems, further strengthens this thesis, as their study showed a 5–10% reduction in CO₂ emissions through digital route optimization. In light of the discussion of market mechanisms, Psaraftis et al. [23] stressed the ambiguity of the effects of taxes and trade quotas on emissions. The results obtained show that without the development of the biofuel sector and LNG infrastructure, such measures could become an excessive financial burden for operators. In this context, the concept of "green corridors," developed by Akhavan [24], which identified the integration of shipping and ports as the foundation of sustainable ecosystems, becomes essential. Additional prospects in

this direction were opened by the work of Klakeel et al. [25], who systematized mature emission-reduction technologies that could serve as a basis for further practical integration. The study by Stathatou et al. [26], which tested biodiesel on a bulk carrier, confirmed that biodiesel significantly reduces CO₂ emissions, but actual efficiency depends on operating conditions. This corresponds to the results obtained, where "Romashka-3" showed a reduction in CO₂ emissions of approximately 18% while simultaneously reducing voyage costs by 5–6%.

The results confirm the need for a systematic approach that combines technical, organizational, and regulatory decarbonization tools. In particular, Karountzos et al. [27] highlight the importance of geoinformatic solutions for achieving zero emissions in coastal shipping networks. This aligns with experimental data showing that digital route optimization can reduce CO₂ emissions by 5–10%, making the integration of information systems a crucial element of the overall strategy. Fu et al. [28] emphasize the role of emission trading policy in selecting the optimal strategy for a liner fleet. The economic effect observed during the transition to "Romashka-3" biofuel aligns with the authors' conclusions: even a relatively small reduction in voyage costs (–5–6%) could be a critical factor if a carbon tax or quotas are implemented. Similar results were obtained by Shabib et al. [29], who, in their review, highlighted the lack of practical integration of technologies in ports as the main barrier to sustainability. In this context, the data on the need for LNG and biofuel infrastructure development fully correspond with the identified issues. The regulatory aspect is reflected in the work of Ghoneim et al. [30], who demonstrated that achieving IMO emission goals directly depends on the effectiveness of the regulatory environment. The integrated energy efficiency index established in the study (0.58 for LNG, 0.63 for biofuel, 0.82 for diesel) serves as a practical tool that can be adapted to the monitoring and reporting system in accordance with IMO requirements.

Wang et al. [31] applied the GA-LSTM algorithm to predict vessel energy consumption, demonstrating the effectiveness of big data analysis in improving the accuracy of emissions estimation. This directly corresponds to the use of FlowTech FT-200 sensors, which helped form an empirical dataset for further scenario calculations. Zhou et al. [32] showed that dual-fuel solutions for tankers significantly reduce emissions based on the Energy Efficiency Design Index, which aligns with data on the advantages of LNG in reducing NO_x and SO_x. In a broader review, Alamoush [33] addressed the repetitiveness of decarbonisation studies in ports, stressing the need for unified methodologies. The integrated approach combining vessel data analysis, test-bench trials, and economic models can be considered an example of such systematisation. New decarbonisation trends are closely linked with the use of renewable energy sources. Balaji and You [34] demonstrated the potential to produce

green hydrogen using offshore wind power to supply coastal shipping routes. Although these technologies were not included in the results presented, they could be the next step in transforming the fuel balance. Similarly, Evingür and Osma [35] examined the prospects of integrating solar photovoltaic systems into maritime infrastructure, aligning with the trend toward creating "green" ports and the concept of green corridors.

The results confirm that implementing alternative fuels and digital management technologies in the operation of marine vessels not only reduces harmful emissions but also optimises per-voyage costs in the medium- and long-term. In the context of previous studies analyzing the potential of biofuels, LNG, and hydrogen solutions, the data obtained aligns with the conclusion that a multi-level approach is needed to modernize maritime transport. Specifically, the observed effects of CO₂ reduction by 15–25%, substantial reductions in NO_x and SO_x, stability in voyage costs when using biofuels, and increased efficiency through digital optimisation of routes and energy consumption indicate the feasibility of a gradual transition to mixed strategies. These findings complement the contemporary concept of decarbonising maritime transport, which involves not only choosing new fuels but also developing infrastructure, digital control systems, and "green" port corridors. The integrated approach developed aligns with leading sustainable shipping concepts. It confirms that the impact of innovative fuels and digital solutions on energy efficiency is systematically determining, from both technical and economic efficiency perspectives, as well as in meeting international environmental standards and the requirements of global decarbonisation.

Conclusions

This study conducted a comprehensive assessment of the impact of different fuel types and energy efficiency strategies on the performance of marine vessels in the context of global decarbonisation. The results of field measurements confirmed that diesel fuel provides relative availability and infrastructure, but is accompanied by high levels of CO₂ (an average of 415 t per voyage), NO_x, and SO_x, as well as significant financial burdens (about USD 33,700 per voyage). Short voyages had the highest cost per kilometre, while long voyages had the highest total emissions, confirming the strategic inefficiency of diesel fleets in the long term. Test-bench trials showed that "Romashka-3" biofuel reduced CO₂ emissions by 19%, NO_x by 27%, and SO_x by 58%, while lowering voyage costs by 6% compared to the diesel scenario. LNG demonstrated the most significant environmental effect: CO₂ emissions were reduced by 20%, NO_x by almost half (–49%), and SO_x by 95%, although voyage costs rose by 6%.

Thus, LNG is the most promising from an environmental perspective, while biofuel represents a compromise option that combines emission reductions with economic benefits. The calculation of the integrated energy efficiency index confirmed the conclusions: diesel fuel received the lowest result (0.82), "Romashka-3" biofuel showed a medium level (0.63), while LNG demonstrated the highest level of environmental efficiency (0.58), despite increased financial costs. It was additionally established that digital route optimization can reduce fuel consumption and CO₂ emissions by 5–10%, and decrease costs by 3–5%, regardless of the fuel type used.

Thus, the study confirmed that no single strategy can be considered a universal solution for decarbonizing shipping. The most balanced option in the short- and medium-term is the transition to biofuels combined with digital optimization technologies. LNG should be regarded as the strategic backbone for future development, requiring significant investment in port infrastructure. Despite its accessibility, diesel is gradually losing viability due to its high environmental footprint and anticipated regulatory restrictions. In the long term, the study's results provide a foundation for implementing a multi-level energy efficiency system, which includes the development of the biofuel sector, LNG infrastructure, digital management, and the creation of "green" port corridors. Further research should focus on analysing larger vessel samples from different regions, incorporating operational data for alternative fuels, and considering infrastructural and macroeconomic factors that define the long-term effectiveness of transitioning to "green" technologies.

References

1. Veshapidze, S., Kereselidze, L., & Tsirdava, N. (2024). Decarbonization of Energy and the Challenges of Sustainable Development in Georgia. *Ekonomisti*, 4. <https://dspace.tsu.ge/server/api/core/bitstreams/30135e73-305c-47b8-8f07-fdfl1c87f7ed/content>
2. Janjghava, R., Tsitskishvili, A., & Tsitskishvili, G. (2025). Implementing Cold Ironing Methods in Georgian Ports. In *Energy Rationality and Management for Decarbonization* (pp. 77-82). Cham: Springer Nature Switzerland. https://link.springer.com/chapter/10.1007/978-3-031-68497-5_3
3. Vadachkoria, G., Tsitskishvili, A., & Tsitskishvili, G. (2025). Analyzing CO₂ Emission: A Case Study of Batumi State Maritime Academy. In *Energy Rationality and Management for Decarbonization* (pp. 491-495). Cham: Springer Nature Switzerland. https://link.springer.com/chapter/10.1007/978-3-031-68497-5_27
4. Díaz-Secades, L. A. (2024). Enhancing maritime sector decarbonization by integrating fishing vessels into IMO energy-efficiency measures. *Journal of*

- Marine Science and Engineering*, 12(4), 663. <https://www.mdpi.com/2077-1312/12/4/663>
5. Nisiforou, O., Shakou, L. M., Magou, A., & Charalambides, A. G. (2022). A roadmap towards the decarbonization of shipping: A participatory approach in Cyprus. *Sustainability*, 14(4), 2185. <https://www.mdpi.com/2071-1050/14/4/2185>
 6. Brown, M. A., Palsule, N., & Hubbs, J. (2024). Anticipating the response of climate solutions to a policy paradigm shift: Case study of the US and the state of Georgia. *Energy Strategy Reviews*, 53, 101411. <https://www.sciencedirect.com/science/article/pii/S2211467X24001184>
 7. Grzelakowski, A. S., Herdzik, J., & Skiba, S. (2022). Maritime shipping decarbonization: Roadmap to meet zero-emission target in shipping as a link in the global supply chains. *Energies*, 15(17), 6150. <https://www.mdpi.com/1996-1073/15/17/6150>
 8. Vakili, S. V., Ballini, F., Dalaklis, D., & Ölçer, A. I. (2022). A Conceptual transdisciplinary framework to overcome energy efficiency barriers in ship operation cycles to meet imo's initial greenhouse gas strategy goals: case study for an Iranian shipping company. *Energies*, 15(6), 2098. <https://www.mdpi.com/1996-1073/15/6/2098>
 9. Tu, H., Liu, Z., & Zhang, Y. (2024). Study on Cost-Effective Performance of Alternative Fuels and Energy Efficiency Measures for Shipping Decarbonization. *Journal of Marine Science and Engineering*, 12(5), 743. <https://www.mdpi.com/2077-1312/12/5/743>
 10. Wang, K., Guo, X., Zhao, J., Ma, R., Huang, L., Tian, F., ... & Wang, Z. (2022). An integrated collaborative decision-making method for optimizing energy consumption of sail-assisted ships towards low-carbon shipping. *Ocean Engineering*, 266, 112810. <https://shortlink.uk/1ssZL>
 11. Microsoft. (2019). *Microsoft Excel* (Version 2019) [Computer software]. Microsoft Corporation. <https://www.microsoft.com>
 12. IBM Corp. (2020). *IBM SPSS Statistics for Windows* (Version 27.0) [Computer software]. IBM Corp. <https://www.ibm.com/products/spss-statistics>
 13. Python Software Foundation. (2023). *Python: Version 3.11* [Computer software]. Python Software Foundation. <https://www.python.org>
 14. 2023 IMO Strategy on Reduction of GHG Emissions from Ships <https://shortlink.uk/1neIX>
 15. Bayraktar, M., Mollaoglu, M., & Yuksel, O. (2025). Scientometric Analysis of Energy Efficiency Indicators in Maritime Transportation: A Systematic State-of-the-Art Review and Implications. *Sustainability*, 17(8), 3612. <https://www.mdpi.com/2071-1050/17/8/3612>

16. Issa-Zadeh, S. B., & Garay-Rondero, C. L. (2025). Decarbonizing Seaport Maritime Traffic: Finding Hope. *World*, 6(2), 47. <https://www.mdpi.com/2673-4060/6/2/47>
17. Baştuğ, S., Akgül, E. F., Haralambides, H., & Notteboom, T. (2024). A decision-making framework for the funding of shipping decarbonization initiatives in non-EU countries: insights from Türkiye. *Journal of Shipping and Trade*, 9(1), 12. <https://shortlink.uk/1st06>
18. Kaiser, R., & Chowdhury, A. M. (2025). Hydrogen-Powered Marine Vessels: A Rewarding yet Challenging Route to Decarbonization. *Clean Technologies*, 7(3), 68. <https://shortlink.uk/1st0a>
19. Shi, J., Zhu, Y., Feng, Y., Yang, J., & Xia, C. (2023). A prompt decarbonization pathway for shipping: green hydrogen, ammonia, and methanol production and utilization in marine engines. *Atmosphere*, 14(3), 584. <https://www.mdpi.com/2073-4433/14/3/584>
20. Avaritsioti, E. I. (2025). Shipping decarbonization: Financial and business strategies for UK shipowners. *Journal of Risk and Financial Management*, 18(7), 391. <https://www.mdpi.com/1911-8074/18/7/391>
21. Barberi, S., Sambito, M., Neduzha, L., & Severino, A. (2021). Pollutant emissions in ports: a comprehensive review. *Infrastructures*, 6(8), 114. <https://www.mdpi.com/2412-3811/6/8/114>
22. Aktas, T. U., Shi, J., Lim, G. J., Prousalidis, J., D'Agostino, F., & Liang, C. (2023, August). Decarbonization of the Maritime Transportation Systems: Recent progress, challenges, and prospects. In *2023 IEEE Electric Ship Technologies Symposium (ESTS)* (pp. 224-230). IEEE. <https://ieeexplore.ieee.org/abstract/document/10220507>
23. Psaraftis, H. N., Zis, T., & Lagouvardou, S. (2021). A comparative evaluation of market-based measures for shipping decarbonization. *Maritime Transport Research*, 2, 100019. <https://www.sciencedirect.com/science/article/pii/S2666822X21000113>
24. Akhavan, M. (2025). Decarbonizing maritime transport: the role of green shipping corridors in making sustainable port-city ecosystems. *Ocean and Society*, 2. <https://shortlink.uk/1st0w>
25. Klakeel, M., Anantharaman, M., Islam, R., & Garaniya, V. (2024, November). Charting a Greener Course: A Review of Mature Technologies for Lowering Vessel GHG Emission. In *Conference Proceedings of INEC* (Vol. 2024). <https://shortlink.uk/1st0q>
26. Stathatou, P. M., Bergeron, S., Fee, C., Jeffrey, P., Triantafyllou, M., & Gershenfeld, N. (2022). Towards decarbonization of shipping: direct emissions & life cycle impacts from a biofuel trial aboard an ocean-going dry bulk

- vessel. *Sustainable Energy & Fuels*, 6(7), 1687-1697.
<https://pubs.rsc.org/en/content/articlehtml/2022/se/d1se01495a>
27. Karountzos, O., Kagkelis, G., & Kepaptsoglou, K. (2023). A Decision Support GIS Framework for Establishing Zero-Emission Maritime Networks: The Case of the Greek Coastal Shipping Network. *Journal of Geovisualization and Spatial Analysis*, 7(2), 16. <https://link.springer.com/article/10.1007/s41651-023-00145-1>
 28. Fu, Q., Wu, J., Xu, H., Zhao, R., & Zhao, F. (2025). Decarbonization Strategy Optimization for Liner Fleet under Emission Trading Policy. *Transportation Research Record*, 03611981251341333. <https://journals.sagepub.com/doi/abs/10.1177/03611981251341333>
 29. Shabib, A., Maraqa, M. A., Mustafa, S., Peng, S., Ma, G., Jia, J., & Qiu, N. (2025). Bridging theory and practice in port sustainability: a critical review of frameworks, technologies, and implementation strategies. *International Journal of Sustainable Engineering*, 18(1), 2538856. <https://www.tandfonline.com/doi/full/10.1080/19397038.2025.2538856>
 30. Ghoneim, N., Colak, A. T., & Amer, A. (2023). Exploring the regulatory framework of maritime decarbonization to achieve IMO GHG emission targets. *Port-Said Engineering Research Journal*, 27(1), 8-14. <https://shortlink.uk/1nemI>
 31. Wang, K., Hua, Y., Huang, L., Guo, X., Liu, X., Ma, Z., ... & Jiang, X. (2023). A novel GA-LSTM-based prediction method of ship energy usage based on the characteristics analysis of operational data. *Energy*, 282, 128910. <https://shortlink.uk/1nemP>
 32. Zhou, J., Wang, Z., Chen, Y., Zhu, H., & Han, Z. (2025). Evaluation of the decarbonization effect of dual-fuel solutions for shuttle tankers using the energy efficiency design index. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, 14750902251339117. <https://journals.sagepub.com/doi/abs/10.1177/14750902251339117>
 33. Alamoush, A. S. (2024). Trends in port decarbonization research: are we reinventing the wheel?. *Current Opinion in Environmental Sustainability*, 71, 101478. <https://www.sciencedirect.com/science/article/abs/pii/S1877343524000654>
 34. Balaji, R. K., & You, F. (2024). Sailing towards sustainability: offshore wind's green hydrogen potential for decarbonization in coastal USA. *Energy & Environmental Science*, 17(17), 6138-6156. <https://pubs.rsc.org/en/content/articlehtml/2024/ee/d4ee01460j>

LOGISTICS AS A SCIENTIFIC TOOL FOR MANAGING FLOW PROCESSES

Teimuraz Gograchadze

Assistant Professor at BNU

Tariel Paksadze

Assistant Professor at BNU

Abstract. This article examines the development of scientific approaches and practical methods in logistics that coincided with Georgia's transition to a market economy. The authors note that certain difficulties arose in developing logistics concepts, primarily due to the difficult economic situation and social tensions across all social strata. The article describes logistics ideas that are fundamentally new to most Georgian entrepreneurs and have not found support in domestic businesses. Stagflation, high levels of monopoly power in key industries, a financial crisis, a rapid decline in production volumes and living standards, ongoing negative economic restructuring, and a decline in investment—this is far from a complete description of the socioeconomic situation in Georgia, which negatively impacts logistics development.

Keywords: Flow processes, flow process management, Georgian logistics market size, flow development potential.

Introduction

As the Georgian economy develops, production processes designed to meet diverse market needs are becoming increasingly important. Logistics methodologies that optimize the entire supply chain—from logistics to product distribution and after-sales support—can ensure the efficient implementation of these processes.

Discussion

The development of scientific approaches and practical methods in logistics coincided with Georgia's transition to a market economy. The development of logistics concepts has encountered certain difficulties, primarily due to the challenging economic situation and social tensions across all sectors of society. For most Georgian entrepreneurs, logistics ideas are fundamentally new and have not found support in domestic businesses. Stagflation, a high level of monopoly in key sectors, a financial crisis and non-payments, a rapid decline in production volumes and living standards, ongoing negative economic restructuring, and a decline in investment—this is far from a complete description of the socioeconomic situation in Georgia, which negatively impacts the development of logistics [1].

The European Commission ranks Georgia 99th out of 150 countries in its logistics development ranking. Both international and Georgian experts agree that logistics in Georgia is a relatively underdeveloped, yet exceptionally promising, segment of the market economy.

Speaking at the International Transport and Logistics Exhibition in Paris in the spring of 2023, the Prime Minister of Georgia estimated the size of the Georgian transport and logistics services market at \$8.5 billion and forecast that this figure could increase by almost 2.5 times, and even three times, by 2030.

Such growth should primarily come from the development of transport and logistics infrastructure, improved quality of logistics services, and improved supply chain management [5].

For a long time, the role of the distribution sector in Georgia was underestimated, even though in the West, supply and distribution occupy a fundamental position in logistics. Initially, service culture in Georgia lagged behind that of the manufacturing sector. Service was characterized by slow movement of goods from producers to consumers, high levels of unmet demand, low reliability, and insufficient customer service. Service was always financed on a residual basis; senior management developed a persistent psychological stereotype of underestimating the role of service in the economy.

Table 1. Development of logistics services in Georgian enterprises (according to questionnaire surveys, % of responses received)

Logistics services	2020	2023	2025
Implemented and developing	40	54	68
Implemented but not developing	44	58	75
Not implemented	16	—	—

The modern environment in which businesses operate is characterized by instability, inconsistency, and unpredictability, which, to a certain extent, devalues long-term forecasts. The low network readiness of Georgian enterprises makes it difficult to respond to changes in real time. Therefore, the problem of managing logistics services amid global competition and the development of information technology in business is objectively moving into the realm of experimental, scientific, and practical work.

Over the past few years, most companies have begun devoting significantly more attention to logistics than before. This is not surprising, as business profits depend on stable supplies and optimal routes. CFOs are increasingly responsible for logistics—they possess the skills that help businesses gain a competitive advantage in this area. At the same time, planning becomes more transparent, allowing the company to remain

profitable through accelerated product turnover, reduced customs costs, and prompt responses to customer requests.

Considering that the main goal of a company's logistics department is to ensure a competitive position in the market, one can speak to the need for logistics departments and the broader development of logistics. Competition in all leading industries is reaching global proportions today, and therefore, organizational management is striving to transform simple logistics supply chains from mere service tools into strategic business assets. This functional component of a company positively impacts the bottom line, including its capitalization. It has not yet become generally accepted that the flexibility and responsiveness of a logistics service are key factors in today's success. However, a small number of companies, having optimized their logistics service, realized that a strategic asset (a competitive advantage in the market) was practically under their noses [3] [7] [11].

Logistics, like mathematics, physics, and the strength of materials, is establishing itself as a universal scientific tool for the rational (optimal) management of any flow processes in a sufficiently developed and productive market economy. Domestic and foreign scientists have accumulated significant experience in developing solutions to economic problems grounded in the theoretical and methodological foundations of logistics. Currently, leading companies have integrated traditional logistics functional areas (transportation, inventory management, purchasing and order management, warehousing, cargo handling, and packaging) on a common information technology platform, creating a strategic innovation system.

Implementing logistics management methods in business practices enables companies to significantly reduce all types of product inventory across production, supply, and distribution, accelerate working capital turnover, reduce production and distribution costs, and ensure the highest possible customer satisfaction with the quality of goods and services.

Table 2 shows how Michael R. Linders estimated the share of logistics costs in product value.

Table 2. Share of logistics costs in various economic sectors

Industry	Industry Share of logistics costs from turnover, %
Food industry	Over 30
Metal production and metalworking	26-27
Chemical industry	20-25
Paper industry	16-17
Woodworking	16-17

Agricultural products	16-17
Electronic and electrical products	16
Textile industry	15
Re-export of machinery	Over 40

As in many other developing sectors, Georgian logistics is oriented toward Western standards. Companies operating in the transportation and logistics market can be divided into several segments based on the quantity and quality of services provided, the degree of integration with the client's business, and market access. With a 1PL² (First Party Logistics) system, a company handles all necessary logistics (raw material procurement, finished product distribution) itself, using internal resources. 2PL³ (Second-Party Logistics) involves providing traditional transportation services or simple warehousing. [8]

Today, the most widespread and responsive level of integrated logistics services worldwide is the 3PL (Third-Party Logistics) model.

3PL providers are logistics operators that manage a full range of services, including transportation, shipping, intermediate and final warehousing, inventory management, document flow, etc. Furthermore, 3PL companies, using information technology, provide management and control over the service delivery process at every stage.

3PL companies, with their own or leased vehicles and warehouse facilities, assume responsibility and risk for moving goods throughout the entire supply chain. They outsource this process, relieving the client of the need to work on this area and acting as an intermediary between the manufacturer and the consumer. 4PL companies are primarily consulting firms that may not even own the logistics infrastructure or transport, but instead focus on integrating all links in the supply chain. Using an information base, the 4PL provider plans, monitors, and manages all operations, acting as a single service provider [9].

But even this level is far from the limit. There's already talk of the next stage of development – fifth-party logistics (5PL), which leverages internet technologies to solve logistics problems.

“Logistics connects people, markets, continents” – this motto from one of the World Logistics Congresses clearly defines the importance of logistics in the modern world. And Georgia's future depends, in no small part, on how quickly and successfully

² **1PL** - is a model where a manufacturer, supplier, or retailer handles their own logistics operations in-house. The firm directly manages its own warehousing, transportation, inventory, and delivery without using external providers. It is typically used by small businesses or large, vertically integrated companies.

³ **2PL** - refers to a model where a company outsources its transportation, warehousing, and shipping activities to a specialized, asset-based provider, such as a carrier or shipping line. Unlike 3PL, the hiring company retains control over supply chain management and inventory planning.

it integrates into the global logistics space, while ensuring the sustainability and security of its supply chains [11].

References:

1. Constantinescu, C., Mattoo, A., & Ruta, M. (2026). Trade Developments in 2026: Policy Uncertainty Weighs on World Trade. World Bank Group. Retrieved from <https://shortlink.uk/1st2d>
2. Gitolendia, B. (2018). "Ways of approximation and further compatibility of the Georgian transport system with the European and International Standards". Tbilisi: Paata Gugushvili Institute of Tbilisi Iv. Javakhishvili State University.
3. Lashkhi, T., Patariaia, G., & Gabrielashvili, A. (2024). "Georgian Railway LLC - Drafting an Analytical Report". Office of the State Minister of Georgia on European and Euro-Atlantic Integration. Tbilisi: Project of Open Society Georgia Foundation.
4. WTO. (2024, January). World Trade Statistical Review 2024. 1, 174. NY, NU, USA. Retrieved from https://www.wto.org/english/res_e/statis_e/wts2019_e/wts19_toc_e.htm
5. Avdaliani, E. (2019, 05 02). Georgia and the Great Silk Road: Myth or Reality? . Tbilisi, Georgia: Forbes Georgia. Retrieved from <https://forbes.ge/news/6161/saqarTvelo-da-abreSumisdidi-gza>
6. Bliadze, M., Sulaberidze, L., & Sharashidze, L. (2024). Development of Transport and Transit Corridors at the International Level and Its Significance. Social Economy Current Problems of the 21st Century (N 3).
7. Government of Georgia. (2025). Government Program "Towards Europe Only with Peace, Dignity, and Prosperity". Tbilisi: Parliament of Georgia. Retrieved from https://www.gov.ge/files/90372_90372_536784_372256.pdf
8. Ministry of Regional Development and Infrastructure of Georgia. (2025). Ministry of Regional Development and Infrastructure of Georgia. (S. R. Ministry, Ed.) Tbilisi, Georgia. Retrieved from http://www.mrdi.gov.ge/sites/default/files/kaxetis_regionis_ganvitarebis_strategia_2014-2021_clebistvis_0.pdf
9. Boris Gitolendia – Analysis of Intermodality Issue of Transportation System of Georgia – International Conference "Technological Innovations for Sustainable Society," Vilnius College of Technologies and Design, Technical Faculty, Vilnius, Lithuania – 2018;
10. Trade and Development Report 2019. Financing a Global Green New Deal. Report by the Secretariat of the United Nations Conference on Trade and Development. United Nations Publications, 2024. 173 p. https://unctad.org/en/PublicationsLibrary/tdr2019_en.pdf
11. Trade: Merchandise exports (current US\$). The World Bank. Available at: <https://data.worldbank.org/topic/trade> (accessed 29.02.2024).

ANALYSIS OF DEATH AND INJURY CASES AMONG GEORGIAN SEAFARERS: MEDICO-LEGAL ASSESSMENT AND RECOMMENDATIONS

V. Imnaishvili

Master of Maritime Law,
Associate Professor at BNU

Abstract. The maritime industry remains one of the most dangerous fields worldwide, especially for citizens of countries with underdeveloped safety and medical systems. This review covers only 11 of 50 cases recorded over five years, from 2020 to 2025, involving Georgian seafarers. It discusses both fatal and disabling incidents, focusing on medical causes, legal classification, documentation, and suggestions to improve safety standards and protect seafarers' rights. The article is aimed at maritime law experts, P&I clubs, consular officials, and crew management professionals.

Keywords: Seafarer death; mortality case; medical aspect; economic aspect.

Introduction

Earlier, studies on seafarers' mortality were carried out by district medical centers. Currently, only personal censuses of interested individuals are available to analyze these issues. According to 2023 data, the average overall mortality rate among seafarers in Georgia was eight times lower than that of fully able-bodied men. Data from district medical centers show that the mortality rate during voyages was significantly lower than between voyages. At the same time, mortality during voyages was mainly caused by circulatory diseases, while neoplasms were the leading cause between voyages.

The profession of a sailor is one of the most dangerous in the world. The work of a sailor in the fishing fleet is comparable in danger to that of a miner or a logger. In 2022, seafaring was recognized as the most hazardous job in the United States, with an annual fatality rate of 121.2 per 100,000 workers, compared to a national average of 3.35. According to the International Labor Organization, the sea claimed 1,051 lives in 2024: 100 seafarers in the fishing industry, 400 in coastal shipping, and over 500 in international shipping.

In addition to the direct threat to life, seafarers' work involves complex exposure to harmful occupational factors. The unique nature of seafarers' work is that ships serve as both a workplace and a residence and recreation space, which means household, socio-psychological, and occupational risk factors coexist in this environment, adversely affecting health.

Mortality and its trends play a crucial role in the set of health indicators because they are the most objective, informative, and quantifiable measures, with their values

less influenced by administrative “corrections” (such as adjusting for the fact of death or a fatal accident on board a ship). However, such “corrections” are sometimes made, for instance, in cases of respiratory diseases or minor injuries.

Analyzing the current state of mortality in the maritime industry, including its gender, age, nosological, and other profiles, as well as mortality trends based on these factors, allows us to identify “problem areas” and develop targeted measures to address them.

The purpose of this study is to propose improvements in medical services for seafarers, based on an analysis of mortality rates among naval personnel served by Georgian medical organizations.

Materials and Methods

The present study used mortality data provided by the BNU Associate Professor and Master of Maritime Affairs, Captain Valerian Nemsadze. The production of statistics was voluntary. Its goal was to address a key issue—medical care for seafarers and mortality prevention. The analysis was conducted without considering gender, focusing only on males (women comprised less than 1% of the study sample and were excluded from further analysis).

The data supplied by Valerian Nemsadze included mortality among seafarers during voyages and between voyages, as well as a summary of annual mortality data for 2024. The mortality indicators analyzed included the casualty mortality rate (CMR)—the number of seafarers who died per 1,000 workers annually—and the cause-specific mortality rate—the number of seafarers who died from a single cause per 100,000 workers. Due to the lack of information on the age distribution of active seafarers in the data from the Maritime Center, it was not possible to analyze age-specific mortality rates or to calculate standardized mortality rates, which would remove the impact of differences in age structures across populations and enable a scientifically valid comparison of mortality between different countries, regions, and maritime centers. Mortality rates were analyzed separately for four job categories:

- 1) Command personnel (CP)—captain, navigator, pilot;
- 2) Ship's Engineering Service (SES)—engineer, electrical engineer, machinist;
- 3) Deck Crew Specialists (DC)—sailor, fish catcher, helmsman;
- 4) Other Ship's Personnel (OP)—service personnel, cook.

Research Results and Discussion

As a result of the medical assessment, it is necessary to determine the main causes of death. As a result of the study of existing cases, it was determined that the main causes of death are:

- Cardiovascular diseases - myocardial infarction, ischemic disease, hypertrophic cardiomyopathy (7 cases);
- Cerebrovascular pathologies - stroke, intracranial hemorrhage;
- Hypoxia - death caused by oxygen deficiency in a closed tank;
- Toxicological poisoning - methadone and diphenhydramine overdose.

In the majority of cases, death is classified as natural, which limits the possibility of compensation. Of the recorded cases, only one was assessed as an accident, and the other as unnatural (drug intoxication).

Diagnostic limitations that exist in the way of establishing the truth of the medical conclusion are as follows:

- The absence of an autopsy limits the accuracy and legal strength of medical conclusions
- Only visual diagnostics (computer tomography) were used
- Most of the sailors had chronic diseases: hypertension, diabetes, renal failure

As for the next group of diseases - traumatism and disability - the picture is as follows:

- Post-traumatic contracture of the ankle - partial disability, limitation of working capacity;
- Hand injury during ship's rollover - Lost Workday Case (first aid was required);
- Chronic renal failure - terminal condition, high risk, although death was not documented;
- Death certificates, apostilles, visual reports, and international certificates — properly prepared;
- The absence of an autopsy in some cases limits the legal justification.
- A responsible person must be appointed to communicate with the family.
- Legal support should be provided in both the flag state and the seafarer's country of nationality (as a recommendation to shipowners and operators).

Table 1. Legal classification and documentation

Death Category	Number of Cases	Legal assessment
Natural Death	7	Limited possibility of compensation
Accident	1	Breach of procedures, compensation possible
Unnatural Death	1	Breach of contract, investigation required
Terminal Condition	2	High risk, medical monitoring required

Source: Compiled by the author

It is necessary to formulate the measures that we consider necessary to take. They will mainly be of a medical and legal nature, since these two pieces of evidence will be the basis for any financial decision that the relevant authorities must make following the death of a seafarer.

Medical measures

- Complete inpatient clinical examination every three years for persons aged 45 and over;
- Mandatory full medical examination before boarding the ship, especially for persons aged 45 and over;
- Monitoring of chronic diseases (hypertension, diabetes, kidney disease) during the voyage;
- Availability of a defibrillator and trained personnel on board;
- Conducting an autopsy in the event of sudden death - for accurate diagnosis and legal protection.

Occupational safety

- Strict control over entry into confined spaces; mandatory use of gas analyzers and personal protective equipment when entering tanks;
- Instructions on behavior during shipwrecks and in everyday life.
- Fixing of furniture and equipment in living areas;

Legal support

- Storage of all medical and visual documents in digital and notarized form;
- Appointment of a person responsible for relations with families in the event of death;
- Transparent compensation procedure - taking into account international standards (ITF CBA, local legislation);

- Legal support in the flag country and the country of citizenship - during the investigation and preparation of documents.

Conclusion

The overall mortality rate of deck personnel is lower than the comparable rate for able-bodied men in Georgia, on average for the same period. This relatively low mortality rate among deck personnel may be related both to the age distribution of service workers and to the potentially low mortality rate of deck personnel.

In the composition of ship personnel mortality, external causes of death and circulatory diseases, as seen by the differences between European and Georgian data, rank first and second. These causes of death in the male population of Georgia are ordered differently.

The analysis of ship personnel revealed a marker of the healthcare system's effectiveness for this group, namely: the need to incorporate the requirements of modern foreign and domestic methodological documents into the practice of specialized medical organizations, as well as the timely approval of draft regulatory legal acts.

Additionally, the analysis emphasizes the need for a systematic approach to medical monitoring, safety procedures, and legal support. The objectives of these recommendations are to reduce risks, ensure transparency in the compensation process, and protect the rights of seafarers.

References:

1. International Labour Organization: World Social Protection Report 2024-26: Universal social protection for climate action and a just transition; available at: <https://www.ilo.org/publications/flagship-reports/world-social-protection-report-2024-26-universal-social-protection-climate>
2. Stephen E Roberts, Detlef Nielsen, Andrzej Kotłowski, Bogdan Jaremin (2014). Fatal accidents and injuries among merchant seafarers worldwide, *Occupational Medicine* 64(4); DOI: [10.1093/occmed/kqu017](https://doi.org/10.1093/occmed/kqu017)
3. [Neil Ellis](#), [Michael Bloor](#), [Helen Sampson](#), Patterns of seafarer injuries, *Maritime Policy & Management. The flagship journal of international shipping and port research*; Volume 37, 2010 - Issue 2 Pages 121-128; <https://doi.org/10.1080/03088830903533742>
4. [Oldenburg](#), M., Herzog, J., [Harth](#), V. (2016). Seafarer deaths at sea: a German mortality study; *Journal of Occupational Medicine*, Volume 66, Issue 2, Pages 135–137, <https://doi.org/10.1093/occmed/kqv153>

IMPROVING THE INTERACTION BETWEEN SEAPORTS AND RAIL TRANSPORT

Valerian Imnaishvili

Associate Professor at BNU

Giorgi Kikvidze

Associate Professor at BNU

This article analyzes the relationship between seaports and rail transport and their influence on port performance. Rail transport plays a key role in freight movement in Georgia. Despite the effects of the pandemic crisis both in Georgia and worldwide, the volume of rail freight moving in and out of ports continues to grow steadily. According to the Georgian Seaport Infrastructure Development Strategy until 2030, this trend is expected to persist. The analysis indicates that seaport performance will largely depend on the efficient operation of rail transport and on its coordination with other transportation modes. The increase in freight traffic to Batumi and Poti ports caused a decline in 2021, mainly affecting containerized cargo. Possible reasons for this include: shipowners refusing to ship cargo by sea; an imbalance in rolling stock; limited railway capacity; inadequate port infrastructure to handle increased cargo volumes; and poor coordination between ports and rail transport. Notably, attention should be given to the lack of clear, well-coordinated interaction between seaport and rail transport, which results in downtime for ships and rail cars, longer cargo handling times, and ultimately delays in delivering goods to recipients. The article emphasizes the importance of improving control and coordination between the port and the port railway station. It also includes a diagram illustrating information exchange within the port. It proposes an integrated information exchange system to address these issues and improve the efficiency of both seaports and rail transport.

Keywords: Seaport, rail cars, rail transport, wagon handling at ports, interaction between the port and the railway station.

Introduction

Rail transport plays a key role in domestic freight transportation in Georgia, significantly affecting seaport operations. Clear and coordinated interaction between related modes of transport at a seaport is essential to its operational efficiency. [1] provides a detailed analysis of the interaction between the seaport and rail transport and proposes a structure for managing rail transport processing at the seaport, clearly linking them to management functions and periods based on their importance in developing management decisions. Key tasks require scientific and methodological

support for their solution, while preceding and related tasks are addressed by management personnel based on their practical experience and strict adherence to instructions. To improve the efficiency of interaction between related modes of transport at seaports, it is primarily necessary to improve the methodology for operational planning of rail transport processing at the port.

Discussion

1. Operational planning of vehicle handling at the port

This type of planning is based on the port's annual cargo handling plan (with quarterly and monthly breakdowns), developed and compiled from the existing cargo base, concluded contracts and agreements, and forecasts. The main goal of operational planning and management is to coordinate the activities of transport process participants, efficiently allocate and utilize port resources to achieve maximum productivity and cost-effectiveness in loading and unloading operations, and implement shift-, daily-, monthly-, quarterly-, and annual plans. The port's main dispatch service plans, organizes, and manages various modes of transport. The following regulatory documents are used in operational planning: the Port Code of Practice, the Transport Charter of Georgian Railways, and the Rules for the Carriage of Freight by Various Modes of Communication. In addition, the Nodal Agreement between the port and the railway station, process diagrams and maps, the annual specialization of handling complexes or berths, vessel-handling standards, standards for optimal concentration of mechanized lines, and existing contracts and agreements with port clients are used [2, 3].

The port's operational schedule is compiled and updated daily by the port's main dispatch service to expand operational planning, determine port capacity, prioritize and sequence vessel handling, calculate the required number of labor and machinery, and optimally organize port operations. Furthermore, the functions of this port service include drafting a shift-daily plan for the port, organizing, managing, and monitoring its implementation during the operational day. The shift-daily plan for the port is the main guiding document directing the port's production work during the planned 24-hour period. The operational day is divided into shifts in accordance with the established (announced) port operating mode. The shift-daily plan for the port is approved by the daily dispatch meeting, with the port's General Director. The daily dispatch meeting is attended by the port's deputy general directors, chief engineer, chief port dispatcher, chief technologist, directors of stevedoring and freight forwarding companies, and heads of enterprises, directorates, services, and departments involved in vehicle handling and port operations. Once approved, the port's daily shift plan becomes a mandatory document for all port operations. This plan is communicated to

those responsible within two hours of its approval.

Stevedoring companies, enterprises, directorates, and departments are required to promptly submit requests, summaries, plans, and other necessary documents and information to the port's main dispatch service. These documents are used for operational planning, accounting, and monitoring of the daily shift plan and vehicle handling.

Railway car handling is carried out under a contract for the delivery and removal of cars between the railway station and the port. The port's main dispatch service plans, coordinates, monitors, and records the handling of rail transport in accordance with the cargo arrival plan at the port, based on the approved cargo flow distribution. In addition, the specified port service is required to communicate the following information to stevedoring companies: the availability of railcars at the station and on the railway, estimated times for railcar delivery and removal, the time and location of shunting operations, and scheduled railcar loading and unloading assignments for the current day.

Developing a plan for distributing railcars for handling is one of the tasks of operational port planning. The purpose of this task is to distribute loaded railcars arriving at the railway station and those located on the approaches to it among the port handling complexes, and to determine the need for empty rolling stock for removing cargo from the port. The solution to this task is based on the following: the distribution plan for vessels among the port handling complexes, the assigned berth specialization, the availability of railcars at the port railway station or on the approaches to it, vessel loading plans, the availability of cargo in warehouses, and the port's production capacity. Unfortunately, at present, this problem lacks both theoretical development and a satisfactory description of practical procedures that would allow it to be solved.

A potential solution was developed at a working group meeting, including representatives from the port's dispatching office and the port railway station. As a rule, the decision is based on the experience of operational management personnel [2, 4].

2. Existing information exchange system at the port

For clear and coordinated interaction between the railway station and the port, mutual information on the arrival dates of ships and trains, as well as current information on cargo, technical, and commercial operations involving vehicles, is required.

Information on trains, ships, and cargo is transmitted by both the port and the railway station in accordance with the vehicle arrival schedule, which is finalized during daily shift planning at a working group meeting.

Preliminary information on the passage of cargo trains for the port is transmitted

by the Far Eastern Railway's information center in real time (the port dispatcher's automated workstation (AWS) program is a self-updating, dynamic network-level program that accurately reflects the current technological situation at a specific control facility at any given time; these facilities may include the railway network, a specific control area, a railway station, a port, or a berth).

The purpose of the port dispatcher's automated workstation program is to automatically process, archive, and store various data related to the loading, unloading, and movement of all transiting cargo. The primary purpose of this program is to create a comprehensive model of train and container cargo arrivals, analyze cargo delivery timelines, and provide information on request at any time.

The existing system for automating information exchange between participants in the transportation process is shown in Figure 1.

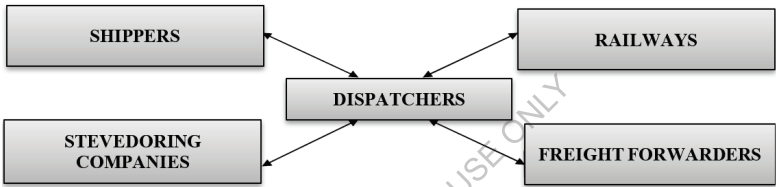


Fig. 1. Information exchange system in the port

3. Improving the Port Information Exchange System

To improve the planning and organization of vehicle handling at the port, as well as the coordinated interaction between the port and rail transport, it is proposed to develop and implement a transport hub information system to ensure effective communication among all participants in the cargo delivery logistics chain.

Such an information system should be implemented in accordance with the principles of an integrated logistics operator across various modes of transport, enabling the efficient organization of the delivery of various cargoes while taking into account the interests of port customers and various carriers. The goal of its creation is to improve the efficiency of the transport hub, ensure coordinated interaction between all participants in the transport process, including rail transport, increase the volume of transshipment of various types of cargo, and improve the speed of transshipment and delivery.

Furthermore, the use of the transport hub information system will improve the efficiency of various vehicles, port-handling equipment and mechanisms, and infrastructure. It will also reduce the cost of loading and unloading operations. Clear

coordination of management processes for the interaction of all links in integrated supply chains will enable the achievement of established goals and, overall, improve the efficiency of transport hub management. This type of coordination is possible through the full utilization of the transport hub's information system, which integrates automated control systems for various modes of transport and participants in freight transportation.

An integrated information exchange system is necessary to address the challenges presented in [1]. Addressing these challenges, which focus on coordinating and developing the logistics infrastructure, will increase freight transport volumes and enhance the sustainability and stability of the supply chain as a whole, including all its links. It should be noted that one of the key functions of this information system is the development of a unified transport hub operation plan, taking into account the financial interests of various participants in the freight transportation process, as well as the study of freight flows and their attraction to the port.

A schematic of the integrated information exchange system is shown in Figure 2.

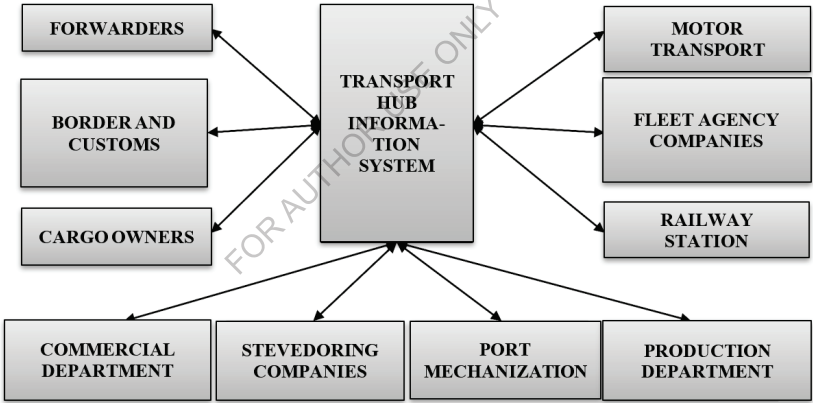


Fig. 2. Integrated information exchange system

The use of principles such as full and comprehensive information exchange among all participants in the logistics chain is a prerequisite for developing an automated “Transport Hub Information System” program.

The automated transport hub information system must enable prompt management decision-making by the dispatcher, monitor the implementation of planned cargo handling targets (in real time), and report any deviations to enable prompt adjustments. The current status of the transport hub in real time requires the

system to include information such as the progress of handling operations at the port berths, the readiness of cargo consignments for loading onto ships, the expected dates and times of arrival of rail and sea transport at the port, the planned timing of cargo operations for arriving vehicles, etc. [5].

Conclusion

Using an information exchange system at the port will eliminate the need for marketing research on emerging cargo flows for up to 15 days, as it allows the use of resources that span from the planning stage to the moment of their formation.

The development and use of this integrated information exchange system will solve the following problems:

1. Accounting for all participants in transport and logistics activities at a specific transport hub;
2. Accumulating a database of cargo flows passing through the transport hub, with the ability to update in real time;
3. Accepting and dispatching various cargo documents scheduled for transshipment at the transport hub;
4. Creating a rough daily plan for distributing fleet and railcars among port handling complexes and berths;
5. Maintaining a digital log of reserve storage facilities (open and closed warehouse areas, berths of port handling complexes, and railway yards) reflecting potential capacity and readiness to receive cargo or vehicles; summarizing statistical information on vehicle handling times at the port and terminal occupancy.

The functionality of the automated information system as a whole will enable coordination of operations between the seaport and rail transport, reduce vehicle downtime at the port, improve the efficiency of both the seaport and rail transport, and reduce cargo delivery times.

References:

1. Branch A.E. Elements of port operation and management/London, New York: Chapman and Hall, 2025. 265 p.2. Cargo Systems № 7
2. Containerisation International Regional Review: North American Ports -August 2023
3. Finnish Rail Administration: Annual Report 2022, 2023
4. International Freightling Weekly № 11 2002
5. Trans Press: magazine of VR Ltd №5 2021, 2022, 2024

6. Kim, K., 1997. Evaluation of the number of rehandles in container yards. *Comput. Ind. Eng.* 32 (4), P. 701-711
7. Lee, B., & Kim, K., 2020. Comparison and evaluation of various cycle-time models for yard cranes in container terminals. *Int. J. Prod. Econ.* 126 (2), P. 350-360
8. Liu, C.I.; Jula, H.; Ioannou, P.A. (2022). Design, simulation, and evaluation of automated container terminals. *IEEE Trans. Intel. Transp.* P. 12-26.
9. Vis, I. (2016). Survey of research in the design and control of automated guided vehicle systems. *European Journal of Operational Research*, 170, P. 677-709.
10. Yang, Y., Zhong, M. & Dessouky, Y. (2018). An Integrated Scheduling Method for AGV Routing in Automated Container Terminals. *Computers & Industrial Engineering*.
11. Luo J. & Wu Y. & MENDES A. (2016). Modelling of integrated vehicle scheduling and container storage problems in the unloading process at an automated container terminal. *Computers & Industrial Engineering*.
12. Stavrou, D., Timotheou, S. & Panayiotou, C. (2017). Assignment and Coordination of Autonomous Robots in Container Loading Terminals. *IFAC-Papers Online*.
13. Grunow, M., Gunther, H., & Lehmann, M. (2016). Strategies for dispatching AGVs at automated seaport container terminals. *OR Spectrum* 28, P. 587-610.
14. Stavrou, D., Timotheou, S. & Panayiotou, C. (2018). Optimizing Container Loading With Autonomous Robots. *IEEE Transactions on Automation Science and Engineering*. P. 1-15
15. Froyland, G. (2018). Optimizing the landside operation of a container terminal. *OR Spectrum* 30, P. 53-75.
16. Gharehgozli (2017) A simulation study of the performance of twin automated stacking cranes at a seaport container terminal. *Eur. J. Oper. Res.* 261: P. 108-128.
17. Dekker R., Voogd, P. & Asperen E. (2017). Advanced methods for container stacking. P. 563-586

STRATEGIES FOR ENHANCING THE COMPETITIVENESS AND ATTRACTIVENESS OF GEORGIA'S BLACK SEA PORTS

Parmen Khvedelidze

Professor at BNU

Dursun Tsintsadze

Professor at BNU

Abstract. This paper analyzes the role and prospects of Georgia's maritime ports within the global container shipping market. The author examines the current state of Georgian ports (Poti, Batumi) and the challenges they face in a highly competitive international environment. The study highlights that while these ports currently serve local and regional cargo flows, their full transit potential remains underutilized due to outdated technical infrastructure and limited integration with the broader transport network.

The article identifies three key components for evaluating port attractiveness: proximity to cargo generation centers, technical connectivity, and the efficiency of the surrounding transport network. Based on an analysis of container flow dynamics in the Asia-Pacific region, the research emphasizes Georgia's significance as an alternative transport corridor. The author concludes that to enhance competitiveness, it is essential to implement deep technological upgrades—including berth deepening and automation—and to form a unified, coordinated transport system that integrates maritime, rail, and road infrastructure.

Keywords: Container Shipping, Port Competitiveness, Transport Corridor, Technical Connectivity, Black Sea Littoral, Asia-Pacific Region, Logistics Infrastructure, Integrated Transport System.

Introduction

The growth of container shipping in the Georgian Black Sea region is primarily associated with the modern development of existing ports. The entry of the Georgian Black Sea region into the container shipping market of North America, Europe and the Asia-Pacific region can only occur in competition with existing players (Japan, South Korea, China, the USA, Canada, Western and Eastern European countries, etc.). Thus, in order to talk about the possibility of integrating the Georgian Black Sea region into the container shipping market, it is first necessary to talk about the competitiveness of the Georgian Black Sea region in this market.

Discussion

Since Georgian ports are primarily engaged in handling cargo flows from nearby Europe and Asia, their transit potential is not fully realized. It is too early to say that Georgian ports are represented in the international competitive environment. It is more accurate to say that ports facilitate Georgian exporters' participation in international commodity markets. Some Georgian ports are not involved in competition at all, but ports are active players in the Georgian market and are only now starting to take steps to enter the international market.

How to determine the scale of competition of a particular port? The answer can be seen in the scale of port transport infrastructure, that is, in the level of integration of the port with the transport network and the list of port users, their number, origin, etc. It is the cargo carriers who assess the attractiveness of the port, choose routes, and transportation parameters.

Against the backdrop of ongoing development and optimization of the transport network in the Black Sea region, the idea of creating new transport transshipment centers capable of taking on a significant share of the cargo flow is attractive.

Research on this topic was conducted by the organizations ERINA and KOTI. As a result of these studies, proposals were formulated:

- On the creation of transport corridors through the Black Sea region of Georgia;
- On the transformation of the Black Sea transport network of Georgia into a transport system.

As part of the strategy for the long-term development of the transport complex of the Black Sea and Atlantic Ocean basins, this idea is based on three transport models:

1. The first model: ensuring domestic transportation + a long-term strategy for the export of fuel and raw materials.
2. The second model: the first model + participation in international transport corridors.
3. The third model: the second model + the creation of its own international and regional transport hubs and business transport centers.

Today, the Black Sea and Atlantic Ocean basins, in particular the Black Sea ports of Georgia, operate within the framework of the first part of these models. If we talk about the international market, they are “invisible” and strong competitors are mobilized around them: the USA, Canada, Germany, Spain, Italy, Great Britain, Turkey, Russia, China, Japan, India, South Korea and others, which occupy 42% of the container transport market of the three ocean basins (Atlantic, Indian, Pacific). Currently, these countries are creating the framework for international transportation, establishing freight routes and determining tariff policies, ultimately creating a

transport network. Therefore, to develop under such conditions, Georgian ports need a competitive strategy to enter the international transportation market.

Of the above criteria for port attractiveness, the most interesting is the criterion “level of port connectivity”, which can be divided into 3 main components: (i) proximity to cargo generation centers, cargo consumption, and main directions of cargo movement; (ii) technical connectivity, i.e. compliance with modern technical requirements in the port (depth, equipment); (iii) efficiency of the surrounding transport network (speed, cost, and quality of cargo distribution).

Let us consider each component of this criterion for the ports of the Black Sea coast of Georgia.

The ports are located in the immediate vicinity of the region's major cargo generation and consumption centers (European countries), along the routes of the main freight highways (Europe-Asia, North America-Asia), and near the main lines of Asia.

As a result of the analysis of a number of sources, as well as in the report CBA (Country Reports of Japan for the Development of an Integrated Shipping and Port System in the Northeast Asia Subregion) on the integrated development of seagoing vessels and port systems by Japan. In 2022, the data presented in Table 2 were obtained.

As a result of the analysis of the data presented in the table, we can talk about the deviation of a number of directions towards Europe, but it should be noted that there are also such directions as Asia - Pacific - Europe, Asia - Pacific - North America, and Europe-West Coast of North America.

Georgia's relations with the countries of the Asia-Pacific region are relatively recent. However, given the significant opportunities that transport development in this region offers, it is worth paying attention to them. Let's consider the dynamics of container flows in the Asia-Pacific region.

Transportation volumes along existing routes to Asia are substantial and continue to grow. The turnover of container transport in this direction at Georgian ports remains low, but it is increasing and has strong prospects. Accordingly, Georgia's Black Sea ports are very attractive as alternative cargo routes.

Table 2. Dynamics of container flows in the Asia-Pacific region (thousands of TFE units)

Country	Year				Ratio of 2022 to 1990
	1990	1995	2000	2022	
China	1217,0	4904,0	19919,0	31885,0	26,19
Singapore	5224,0	11846,0	17096,0	16986,0	3,25
Japan	8107,0	10923,0	13749,0	14044,0	1,73
South Korea	2348,0	4849,0	9072,0	11629,0	4,95
Taiwan	5451,0	7849,0	10511,0	11605,0	2,13

Malaysia	901,0	2101,0	5278,0	8888,0	9,86
Indonesia	924,0	2786,0	507,0	5747,0	6,22
Thailand	1078,0	2156,0	3563,0	4173,0	3,87
Philippines	1408,0	2352,0	3479,0	3765,0	2,67
Vietnam	39,0	893,0	1834,0	2281,0	58,48
Hong Kong	5101,0	1255,0	181,0	1914,0	3,75
Brunei	1,0	71,0	26,0	70,0	70,00
East Asia All	318,0	63352,0	10777,0	130346,0	4,10
India	746,0	1451,0	2515,0	3339,0	4,48
Sri Lanka	584,0	1029,0	1733,0	1765,0	3,02
Pakistan	390,0	551,0	775,0	943,0	2,42
Bangladesh	107,0	245,0	475,0	573,0	5,34
Myanmar	5,0	70,0	20,0	65,0	14,16
South Asia All	1832,0	3346,0	5518,0	6685,0	3,65
Asia All	33632,0	66698,0	113288,0	137031,0	4,07

The competitiveness of the port in terms of technical connectivity is the availability of modern capabilities necessary for cargo handling, storage of goods, and transport operation, as well as the provision of the necessary capacities for the operation and development of the port itself as a whole, and in terms of technology, the presence of modern information systems. For example, according to the data, to receive a modern class linear container ship (Super-Post), with a capacity of 8000 TFE units, the berth depth should be 16 meters and the length approximately 200-220 meters. For fast processing of the ship, the necessary container-handling equipment should operate at 50-60 TFE units per hour, and the entire system for organizing cargo operations should be automated.

In terms of technical capabilities, today, the most developed port in Georgia is the Poti terminal. The depth of its berth and the warehouse area allow it to receive ships with a capacity of up to 3200 TFE. The handling equipment is designed to work with ships with a capacity of 1800 TFE. The port of Batumi can receive ships with a capacity of up to 700, and if the project to construct a new Georgian port, Lazika, is completed, it will be able to receive ships with a capacity of up to 1,400 TFE. It is obvious that none of the existing Georgian ports meets the modern requirements for technical equipment. The modern ports of Batumi and Poti were built in accordance with the standards of the 60s of the last century. Since then, most of the cargo has become transported in containers, so the need for open warehouses arose, which was replaced by the 3rd generation of container ships. The equipment of our ports is catastrophically outdated - currently 80 out of 100 cranes in the port of Batumi are operated after the expiration of their service life.

But it should be noted that in all ports it is possible to reconstruct the port and optimize its operating systems. So, in the port of Batumi, an increase in the number of berths by 45% made it possible to increase the port's load to 50%, while the load of the remaining berths was less than 30%. At the same time, these measures are not enough to enter the transport market of the Asia-Pacific region. Serious re-equipment and development of ports is necessary, for example, as in Turkey, where active port construction is currently underway. Thus, the bottom of the port of Istanbul is being deepened in various places from 4 to 14 meters.

In terms of the efficiency of the surrounding transport network (speed, cost, quality of cargo distribution), all Georgian ports have relatively limited access to the incoming railway and road networks. Currently, the capabilities of ports are largely limited by their surrounding transport infrastructure. The development of this infrastructure is vital. The attractiveness of a port, in terms of the surrounding transport network, does not depend on the port itself, but on the transport infrastructure surrounding the port.

Conclusion. Currently, the development of Georgian ports is largely limited not only by the technical capabilities of railways and roads, but also by external transport companies.

We believe that the unification and joint, coordinated operation of Georgian ports, the joint development of railway, road and aviation transport enterprises will allow seaports to significantly increase their interconnection and, accordingly, their overall efficiency and profitability. Ensuring the positioning and functioning of Georgian ports on the international market as a unified transport system will significantly increase the attractiveness of the ports themselves and the entire Georgian transport infrastructure.

References:

1. Ballou, Ronald H. Business Logistics Management. Prentice-Hall International, Inc. 2009. - 681 Cooper J., Browne M., Peters M. European Logistics: markets, management, and strategy. Oxford, Blackwell Publishers, 2011.-331 c.
2. Copacino, William C. Supply Chain Management. The Basics and Beyond. APICS, 2007. - 204 c.
3. International Journal of Operations and Production Management. -2012.-vol.5.-C.18.
4. APICS Certified Supply Chain Professional: Learning System: Version 2.2. Module 1. Supply Chain Management Fundamentals. - Chicago: APICS, 2017. - 227 p. - Bibliography: p. 204-208. - Cumulative Course Index: p. 208-227. - 2183-13. <http://www.apics.org/credentials-education/credentials/cscp>

5. Daft, Richard L. Management, 2018. – 863 c.
6. Grant Robert M. Contemporary Strategy Analysis, 2012. - 537 c.
7. Porter M., Bond G. Innovative Capacity and Prosperity: the Next Competitiveness Challenge in the Global Competitiveness Report. – NY, 2011.
8. M. Christopher: Logistics & Supply Chain Management: Creating Value-Adding Networks, Prentice Hall, 2010.
9. Strategic management, H. Igor Ansoff, Wiley, New York, 1979. No. of pages: 236.
10. Troy T. Kirby. The Duke of Wellington and the Supply System During the Peninsula War, CreateSpace Independent Publishing Platform, 2024.
11. Smith, J.E. and Nau, R.F. «Valuing risky projects: option pricing theory and decision analysis», Management Science, 41, 795-816, 2015.
12. Trigeorgis, L. Real Options, Cambridge, MA: MIT Press, 2017.
13. Cooper J., Browne M., Peters M. European Logistics: markets, management, and strategy. Oxford, Blackwell Publishers, 2011.-331 c.
14. Copacino, William C. Supply Chain Management. The Basics and Beyond. APICS, 2007. - 204 c.
15. Industrial Marketing Management (Elsevier Science) 32 (2): P. 139-149.
16. Shapiro, J.F. Modeling the Supply Chain. DUXBURY, Thomson Learning, 2011. - 586 c. 111.
17. Goss R. British ports policies since 1945// Transport, economy and policy. 2008. - № 1, 326-333;
18. Estache A., Strong J. The Rise, the Fall, and the Emerging Recovery of Project Finance in Transport//The Washington D.C.: The World Bank, 2010. 38 p.
19. Word, J. M. Integrated Business Processes with ERP Systems (Pr) [Text] / Jeffrey Word, Simha R. Magal. – New York: John Wiley & Sons Inc, 2010- 08-16, Prl, 2018.
20. Clemen, R. Making Hard Decisions, Duxbury, 2016.

THE ROLE OF PPP FOR A TRANSITION TO GREEN PRACTICES IN THE MARITIME INDUSTRY

George Gabedava

Professor at Batumi Navigation University

Nino Tchilaia

Associate Professor at Batumi Navigation University

Abstract. Over the last few decades, the global economy has experienced three major waves of change, one of which was triggered by global climate change and aimed at creating a greener world economy, which is unachievable without greening the maritime industry. Taking into account the significance of the maritime industry in international trade, its role in Georgia's economy, growing environmental concerns, and Georgia's course toward creating a sustainable and green economy, the aim of this paper was defined. The paper analyzes the importance of a collaborative approach to transitioning to green practices in the maritime industry and explores various Public-Private Partnership models and their prior applications across several countries. The article examines Georgia's actions in this regard and, drawing on best practices and other countries' experience, offers recommendations. To conclude, the article aims to show that working in partnership with industry players is a major driver for developing countries such as Georgia to attain a sustainable economy by implementing green practices in sectors that strongly affect the country's socio-economic development.

Keywords: Maritime transport, green economy, sustainable economy, green logistics, public-private partnership

1. Introduction

The maritime industry is a significant part of the global trade system and continues to play a vital role in national and global economic growth and in building strong relations between territories. About 80% of the world's cargo is transported by sea (UNCTAD, 2023). Global container traffic is growing at about 381 million TEU per year, and in the coming years, an average growth of 4% is expected in 2025 (World, 2024). As the need for trade and the movement of goods increases, the efficiency of maritime transport becomes more crucial. Freight transportation accounts for the largest share of logistics emissions; thus, as container traffic rises, environmental impact increases, and the maritime industry faces growing pressure.

Maritime transportation has negative environmental impacts, including air pollution, greenhouse gas emissions, oil and chemical spills, dry bulk cargo releases, garbage, underwater noise pollution, and so forth. Therefore, shipping is an essential component of any program for future sustainable economic growth. Following the adoption of the Sustainable Development Goals (SDGs) in 2015 by the United Nations,

the maritime industry became one of the key stakeholders, playing an important role in contributing to global sustainability. Promoting sustainable shipping and maritime development has been a major priority of the International Maritime Organization (IMO) in recent and coming years.

According to the International Maritime Organization (IMO), energy efficiency, new technology and innovation, maritime education and training, maritime security, maritime traffic management, and the development of the maritime infrastructure will underpin the development of a green and sustainable global maritime transportation system.

In line with the SDG Strategy, the IMO works hard to support its member states in implementing the 2030 Agenda. In response to it, based on the recent report issued by the IMO, more than 50 international instruments were adopted, which, together, create a regulatory framework that ensures shipping is safe, secure and environment-friendly; Several emission control areas were designated; Binding energy-efficiency regulations and standards were designed to address GHG emissions throughout industry (Maritime transport accounts for 3% of all greenhouse gas emissions, primarily carbon dioxide and the indicator has risen 20% over last decade (UNCTAD, 2023)), etc. (IMO, 2020). In addition, the MARPOL convention is widely used to prevent marine pollution from ships caused by operational or accidental factors.

Reducing environmental impact and widely implementing the principles of sustainable development are two of the most pressing tasks in the world. Governments in every country recognize the need to accelerate the green transition. Despite many available tools for addressing climate change, government efforts are falling short (Friday, 2022). Creating new green pathways will require long-term commitment, and different countries opt for different approaches, one of which is the commonly applied Public-Private Partnership (PPP). The experience showcased that ports are among the main areas of responsibility for public authorities, and a sound partnership with the private sector could bring significant added value in terms of efficiency and quality of service. Hence, striving toward a green economy and sustainable growth has brought together the public and private sectors and civil society. Collaborating for the green transition underscores the necessity of collective action and strategic partnerships among all stakeholders in the maritime sector, from shipowners and builders to regulators and technology providers. Therefore, PPP has become vital for creating an ecologically friendly and sustainable maritime industry. Many empirical studies have examined PPP practices to explore several aspects of green initiatives in the maritime industry. The data showed that low-income countries mainly focus on logistics infrastructure and transport facilitation, while middle-income countries intend to improve logistics skills and services as well as trade regulations. High-income countries, on the other hand, put more emphasis on green logistics and information

systems. This means that richer regions have greater opportunities to promote sustainable development (Mingxuan, 2019).

2. Research Findings and Analysis

A PPP is a widely used model for developing different sectors. A PPP can be designed to allow the government to retain its primary regulatory role, while the private sector injects investment and expertise into infrastructure projects. Governments look to the private sector for several reasons, including setting minimum standards for quality services and legal regulation, strengthening the existing sector, widening the range of services, and introducing private-sector technology to improve operational efficiency.

PPPs in the maritime industry have become a means of managing port operations more effectively, developing new port infrastructure, and supporting the implementation of new technologies and standards. The private sector, with access to technology, supports the development of projects that aim to use fuel more efficiently, adopt alternative energy sources, and introduce anti-pollution technologies and management systems, which reduce the environmental impact of maritime transport. The public sector is responsible for providing regulations, laws, technical regulations, political support, and financing mechanisms, and for stimulating the creation of incentives for greening projects. Coordinated work between the two aforementioned sectors contributes to the effective and rapid development of green technologies and to strengthening environmental standards in the maritime industry.

There are several PPP models that depend on the level of public and private involvement in construction, equipment, daily operations, or service provision. Based on the literature and articles in the maritime industry, 4 main models can be distinguished that govern the partnership between the public and private sectors. These are:

1. **Public Service port**, which was a common model till the 80s, was dominant before globalization. In this model of PPP, the port (infrastructure, equipment) is under the state ownership and authority. The port can be local, regional, national, or a mix of all three and is managed by a single organization. In public service ports, the private sector acts as a service provider for some secondary activities, such as port operations. The public service port could suffer from a lack of internal competition, potentially leading to inefficient port administration and a lack of innovation.
2. **The Tool Port**, which is similar to the Public Service Port, is often used as a transitioning step from the Public Service Port to the Landlord Port. In this PPP model, all port investment is managed by the state, while the private sector is responsible for cargo operations and is involved in port organization. Currently,

the Tool Port model is widely adopted in many countries as a way of transferring some public tasks to the private sector (Pallis, 2022).

3. **The Landlord Port**, which is the most dominant model used in large and medium-sized ports in recent years. In this PPP model, management responsibilities are delegated to the private sector, particularly terminals, which are leased to private operating companies, with the port authority retaining ownership of the land. The private operator is also responsible for providing terminal equipment to maintain operating standards.
4. **The Private Service Port**, which is entirely privatized, with the public sector retaining a standard regulatory oversight. Public entities can still be shareholders. It is the least commonly used model at present. Today, the Private Service Port model is generally limited to specific cases, entrusting the private sector with some governing functions (regulatory, port operations, planning, organization, etc.).

Based on a detailed analysis of each party's roles and participation levels in the PPP, a RACI matrix was developed to clarify the distribution of duties across PPP models.

The aforementioned models are reflected in Public-Private Partnerships contracts, which vary in form and conditions according to context, parameters, project constraints, the degree of contribution required from each partner, the level of risk transfer and investment, and the desired outcomes. According to reports from the World Bank and the Asian Bank, various types of public-private partnership contracts are feasible in the maritime industry. The most widely used contracts include service contracts, management contracts, affreightment or lease contracts, Build-Operate-Transfer (BOT) and similar arrangements, and concessions.

Based on the literature review and analysis of various reports, articles, and studies, we can conclude that the green transition proceeds more smoothly at PPP ports than at traditional public ports. The phenomenon can be explained by differences in the speed of innovation implementation, capital investment, flexibility, risk-taking, and stakeholder collaboration. In the case of PPP ports, private operators are involved and tend to introduce cutting-edge technologies to minimize cost and environmental impact.

They are flexible in decision-making and risk-taking, and they make high capital investments in activities that can generate high returns on investment and align their goals with long-term sustainability objectives to attract eco-conscious customers. Traditional public ports lack innovation and flexibility; they are risk-averse, focusing on proven technologies and strictly adhering to government guidelines.

Table 1. PPP Role Matrix in Port Management

Activities	Public service port		Tool Port		Landlord port		Private port	
	Public	Private	Public	Private	Public	Private	Public	Private
Ownership	√		√		√		√	
Port administration	√		√		√			√
Nautical management	√		√		√	√		√
Port infrastructure	√		√		√	√		√
Cargo handling	√			√		√		√
Pilotage	√	√	√	√	√	√	√	√
Towage	√	√	√	√	√	√		√
Mooting services	√	√	√	√	√	√		√
Dredging	√	√	√	√	√	√	√	√

They lack large-scale sustainability initiatives and are more conservative in making green decisions due to bureaucratic processes and dependence on government regulations and budget. They often align their sustainability goals with government policies, which can change with political cycles. All these hamper the allocation of funds for green initiatives and the implementation of green practices. To prove our assumption, we decided to outline the key differences between PPPs and traditional ports in their green transition efforts, using examples from European and Black Sea ports.

To summarize, PPP ports are more agile, more innovative in the green transition, and better aligned with long-term sustainability goals, whereas traditional ports focus more on regulatory compliance and gradual improvements and face more bureaucratic hurdles; they tend to prioritize meeting national regulations rather than pursuing ambitious long-term sustainability.

World port sustainability reports and various port reports show that the use of resource-saving technologies in the maritime industry also brings cost benefits. It helps decrease energy costs by 10-40% and fuel costs by up to 30-50%, reduce material stocks by 40-60%, increase asset turnover by 20-40%, cut transportation costs by 7-20%, lower loading-unloading and storage costs by 15-30%, and decrease other operating expenses by 10-15%.

Table 2. Difference in Green Transition approaches between PPP and Traditional Ports

Criteria	PPP port	Traditional port
Speed of Innovation	Port of Rotterdam (Netherlands) invested in renewable energy, such as onshore power supply (OPS) for ships, and hydrogen projects through partnerships with private companies. The port has also pioneered initiatives like carbon capture and storage (CCS) to reduce emissions (Ecoports, 2023).	Port of Koper (Slovenia) installed solar panels and modern equipment to reduce emissions, but faced delays in securing funding and regulatory approvals for larger-scale green projects (Ecoports, 2023).
Capital Investment	The Port of Mersin (Turkey) has driven substantial investments in green technologies, such as energy-efficient port equipment and automation systems, waste treatment, and carbon emissions reduction. This has allowed the port to modernize rapidly, adopt sustainable practices, and position itself as a green port in the Mediterranean.	Port of Odesa (Ukraine) has improved waste management and reduced emissions through modernized port equipment. However, its transition has been slower than that of PPP-managed ports due to limited public funding and the lengthy approval process for major green investments (Black, 2022).
Flexibility	The Port of Antwerp (Belgium) has implemented innovative green projects, such as hydrogen-powered vessels and an ambitious goal of becoming climate-neutral by 2050. The port is a testing ground for sustainable technologies (PIONEERS, 2024).	The Port of Limassol (Cyprus) has adopted basic environmental measures, such as waste management and emissions-reduction programs, but large-scale innovations, like automation and electrification of port operations, have been delayed due to the conservative nature of public-sector decision-making.
Risk-Taking	Port of Zeebrugge (Belgium) has adopted an ambitious green strategy, including investment in LNG bunkering infrastructure and hydrogen-based fuel systems. Private involvement has enabled the port to take risks in experimenting with alternative fuels and energy sources (DNV, 2020).	The Port of Gdansk (Poland) has made progress on basic green initiatives, such as energy-efficient lighting and emissions reductions. However, the port has been slower to invest in more ambitious technologies, such as renewable energy and electrification, due to the public sector's cautious approach to risk.
Long-Term Sustainability Goals	Port of Burgas (Bulgaria) has integrated long-term sustainability goals into its strategy, including plans for further investments in renewable	Port of Varna (Bulgaria) 's sustainability goals are tied to Bulgarian government policies and EU regulations. While it aims to reduce emissions and improve waste

	energy and continued emission reductions. The port has set ambitious goals for reducing its carbon footprint over the next decade (Black, 2022).	management, the port's ability to pursue more aggressive green targets is constrained by public-sector budget constraints and slow decision-making processes (Black, 2022).
Collaboration and Stakeholder Engagement	The Port of Tallinn (Estonia) has adopted shore power and sustainable cargo-handling systems , thanks to efficient collaboration between public authorities and private investors (DNV, 2020).	Port of Novorossiysk (Russia)'s most notable green initiatives, such as improving waste disposal and limiting air pollution, have been reactive to government mandates rather than proactive green innovations (Black, 2022).

The issues mentioned are also relevant for Georgia. As an IMO member since 1993, Georgia has further developed its strategy following the signing of the Euro-Association Agreement, focusing on sustainable development and a green economy. The country has begun laying the groundwork to integrate the SDGs into its national development plans and multi-sector strategies. Experts state that the green economy includes six main sectors, one of which is clean transport and green infrastructure.

Therefore, measures to promote greener transport have been incorporated into Georgia's 2023-2030 National Transport and Logistics Strategy. Georgia's strategic location as a gateway to Europe and Asia offers opportunities to integrate into the global logistics network and transform into a logistics hub for efficient access to world markets. Historically, the development of international trade has depended on the growth of transportation systems, especially maritime transport.

Currently, maritime transport is one of Georgia's most vital economic sectors, impacting regional and national socio-economic development. The country's transport policy aims to develop more sustainable and environmentally friendly transport systems, aligned with EU and UN standards, including those of ICAO and IMO. Green logistics practices are positively associated with sustainable economic growth, a priority for Georgia, and achieving this goal depends on greening the maritime industry. The development of the maritime sector should align with the country's environmental priorities and international commitments. Promoting eco-friendly transportation and green logistics is a top priority for reducing environmental impact and ensuring sustainability. Georgia's maritime industry encompasses all organizations involved in sea-related activities, ships, maritime trade, and seafarers, including:

- Maritime Transport Agency, the regulatory body for Georgia's maritime sector
- Ports engaged in cargo loading/unloading, sorting, warehousing, etc.
- Higher education institutions and vocational colleges providing maritime education
- Logistics companies offering passenger and cargo maritime transportation

- Various maritime-related businesses like crewing, insurance, financial and legal services, ship accounting, and consulting services

It is worth noting that the Government of Georgia viewed PPP as a catalyst for developing the maritime industry, adopting sector regulations, and meeting international standards. As a result, there are four ports in the country, all operating under PPP contracts:

1. Batumi Port – a landlord port. Since February 2008, a Build-Operate-Transfer (BOT) PPP agreement has been in place between the government and JSC "Kaztransoil"—Batumi Industrial Holding LLC, a subsidiary company. The LLC purchased 100% of the Batumi Oil Terminal shares and received exclusive rights to control Batumi Sea Port for 49 years. The goal of the PPP was port development, asset renewal, and the adoption of modern quality management and safety standards.
2. Poti Port – Georgia's largest port and another example of a landlord port. In 2008, 51% of Poti Port shares were acquired by the UAE-based company RAK Investment Authority (RAKIA) under a BOT agreement, granting it management rights for 49 years. Later, the company bought the remaining shares, becoming the full owner. The PPP aimed to modernize the port, develop the free economic zone, and build a new airport. In April 2011, 80% of Poti Port shares were sold to APM Terminals, a subsidiary of the Danish giant AP Moller-Maersk Group, which was granted port management rights.
3. Supsa Oil Terminal – a private service port owned entirely by British Petroleum.
4. Kulevi Terminal – owned by Socar and an example of a private service port.

Despite over 15 years of PPP experience in the maritime industry and several initiatives planned or underway in Georgia's seaports, the sector's PPP remains in its early stages of development. According to port authorities, since 2008, over \$400 million has been invested in Poti Port and more than \$100 million in Batumi Port to introduce ecological standards, implement energy-efficient technologies, and improve port infrastructure, to reduce emissions and energy consumption. Activities include:

- Developing waste management systems at Poti Port.
- Implementing ecological standards and energy-efficient technologies in Batumi and Poti ports.
- Developing LNG terminals at Batumi Port.
- Expanding and renovating the container terminal to increase throughput and reduce ship waiting times.
- Implementing ERP, WMS, and TMS systems and training port staff.
- Modernizing equipment to speed up container handling.
- Establishing single-window systems in ports and customs.

It is also important to note that the government works closely with other stakeholders in the maritime industry, including higher education institutions and vocational colleges. Since 2016, educational curricula have been revised several times to align with international standards, including courses on environmental issues such as ecological safety, digital navigation, cybersecurity, and maritime labor conventions. Furthermore, the government emphasizes developing the entire logistics network and greening road transport.

Since 2017, Georgia has been adopting modern European air quality control standards, including periodic mandatory vehicle inspections and corresponding legislative changes to improve emissions control. Throughout all processes in the maritime sector, the Maritime Transport Agency of Georgia actively participates and is responsible for implementing organizational and legal measures in accordance with both national and international requirements.

There are no large-scale PPP projects focused on greening the maritime industry in Georgia. While steps have been taken, green stimulus measures fall far short of what is needed, and there is still a long way to go to reach sustainability in the maritime sector.

Green concepts are new to the country, but Georgia has great potential to adopt a stronger, more ambitious approach that will yield more significant results. The private sector plays a critical role but needs stronger incentives to contribute, and the government bears responsibility for leading. During the research, we identified successful practices from different countries that could be adapted and applied in Georgia to green the maritime industry. These initiatives are summarized in Table 3.

According to the Environmental Performance Index (EPI), which examines and compares the sustainability of 180 countries using 58 performance indicators across 11 environmental issues, Georgia occupies an intermediate position among countries. In 2024, it ranked 113th in the air quality category, 63rd in the solid waste category, 94th in the water resources category, and 85th in the air pollution category. There is slight progress compared to 2022, but gargantuan efforts are required to mitigate climate change, improve environmental health, and protect ecosystem vitality.

Applying the practices listed in Table 2 in the maritime industry can directly tackle the problem. Georgia has great potential for rapid improvement and successful implementation of green approaches in the maritime industry, but it requires significant investment that goes far beyond current levels. Therefore, coordinated action by powerful interest groups is required, and PPP remains an essential tool on the path to the green transition.

Table 3: Initiatives for further advancement in Green Transition

Initiative	Example	Action
Shore Power Facilities	Norway and Germany have implemented shore power extensively.	Install shore power facilities at the ports of Batumi and Poti to allow ships to turn off their engines and use electricity while docked, reducing emissions and noise.
Alternative Fuels	The Netherlands and Sweden support the use of LNG and are exploring hydrogen as a marine fuel.	Develop infrastructure for LNG bunkering and explore the feasibility of hydrogen fueling stations. Encourage the adoption of LNG-powered or hybrid ships.
Electric and Hybrid Vessels	Norway's fleet includes electric ferries and hybrid vessels.	Promote the use of electric and hybrid vessels through incentives and subsidies. Facilitate the electrification of smaller vessels operating in and around the ports.
Renewable Energy Integration	Denmark utilizes wind energy to power port operations.	Integrate renewable energy sources, such as solar and wind, to supply power for port operations, reducing reliance on fossil fuels.
Digitalization and Smart Port Technologies	Germany is investing in digital solutions to optimize port operations.	Implement smart port technologies to enhance efficiency, reduce idle times, and optimize logistics. Use data analytics for better environmental management and decision-making.
Waste Management and Circular Economy	The Port of Rotterdam promotes circular economy practices.	Develop comprehensive waste management systems to handle ship-generated waste, including recycling and proper disposal. Encourage circular economy initiatives within the port operations.
Green Port Certification and Standards	Ports in Sweden and the Netherlands often adhere to stringent environmental standards.	Establish and enforce environmental standards and guidelines for port operations and receive EcoPorts status.
Collaboration and Partnership	European ports often collaborate with research institutions and the private sector.	Foster partnerships with international organizations, research institutions, and private companies to bring groundbreaking green technologies and best practices to Batumi and Poti ports.
Policy and Regulatory Support	Scandinavian countries have strong government policies supporting green maritime transport.	Work with the Georgian government to develop and implement policies that support sustainable port operations and green maritime transport. This could include tax incentives, grants, and regulations aimed at reducing emissions. By adopting these strategies, the ports of Batumi and Poti can significantly reduce their environmental impact and contribute to the global effort to green maritime transport.

Conclusion. Greening the maritime industry is a prerequisite for a green economy, as it can indirectly support sustainable development and poverty reduction. In developing countries such as Georgia, the traditional port and maritime industry lacks robust mechanisms to address numerous problems that hinder its greening. The Government must lead and step up to meet the sustainability challenge, while the private sector must assist to create actionable outcomes and impact. In the PPP ports, green technologies are adopted more quickly, the transition to green is progressing smoothly, and the results achieved are comprehensive. Hence, the formation of an efficient and environmentally friendly maritime sector in Georgia depends on aligning and streamlining mandates that promote robust public-private partnerships (PPPs) in the coming years.

References

1. Asian (2014), “Public-Private Partnership Handbook”, Asian Development Bank, retrieved from
2. Black (2022), “Port State Control in the Black Sea Region”, Black Sea Port State Control Secretariat, Annual Report 2022
3. DNV (2020). “Ports: Green gateways to Europe”, retrieved from <https://sustainableworldports.org/>
4. Ecoports (2023), “Environmental Report 2023”, Eco Ports in Sights, retrieved from <https://www.espo.be/media/ESPO%20Environmental%20Report%202023.pdf>
5. Friday, C. (2022) “Six Ways That Government Can Drive the Green Transition”, EY, retrieved from <https://clck.ru/3T3fn5>
6. GOV (2019), “Clean maritime plan: Maritime 2050 environment route map”, retrieved from <https://goo.su/Yd78u>
7. Habsi, S. (2022), “The Role of the Public-Private Partnership (PPP) in Achieving the Optimal Economic and Social Benefits Through the Port Sector” International Journal of Management Science and Business Administration Volume 8, Issue 5, pp. 57-65
8. IMO (2020), “IMO and Sustainable Development Goals”, International Maritime Organization, retrieved from <https://www.imo.org/en/MediaCentre>
9. Khan, S. (2018), “Green Supply Chain Management, Economic Growth and Environment: GMM-based Evidence”, Journal of Cleaner Production. 2018; pp. 588-599
10. Mingxuan, L. (2019), “Green Transportation and Logistics Performance: An Improved Composite Index”, retrieved from <https://www.mdpi.com/2071-1050/11/10/2976>
11. Ministry (2022), “Georgia’s Transport and Logistics Strategy 2023-2030”, Ministry of Economy and Sustainable Development of Georgia

12. Pallis (2022), Port Economics, Management and Policy, Chapter 4.1 Port Governance and Reform, retrieved from www.porteconomicsmanagement.org
13. PIONEERS (2024), “portable Innovation Open Network for Efficiency and Emissions Reduction Solutions” <https://pioneers-ports.eu/>
14. UNCTAD (2023), “Review of Maritime Transport 2023”, retrieved from <https://unctad.org/publication/review-maritime-transport-2023>
15. Worl (2016). “Leases and Affermage Contracts”. World Bank Group. Retrieved from <https://ppp.worldbank.org/public-private-partnership/agreements/leases-and-affermage-contracts>
16. World (2024). “Regional Disruptions Drive Changes in Global Container Port Performance Ranking”, retrieved from <https://www.worldbank.org/en/news/press-release/2024>

FOR AUTHOR USE ONLY

CARBON AND ITS IMPORTANCE

Tamila Ardemanashvili

Doctor of Biology

Associate Professor at BNU

Abstract. Chemistry is a necessary and important science for the development of various fields. The development of individual fields is mainly guided by “applied chemistry”, which, based on the theories of “pure chemistry”, addresses practical applications. Of the elements placed in Mendeleev's periodic system, there are very important elements - carbon, hydrogen, oxygen, nitrogen, without which life is unthinkable. There are other elements necessary for the body, as well as elements with negative properties - toxic, radioactive. Carbon is a very important chemical element that is found in both organic and inorganic compounds. Carbon constantly circulates in the human body. In nature, carbon occurs in the Earth's crust as diamond and graphite. Organic compounds of carbon are characterized by strong covalent bonds that participate in biological cycles and can significantly affect them. Carbon forms several chemical compounds. At high temperatures, it combines with many elements, exhibits strong reducing properties, and is therefore widely used in metallurgy. One of the alloys of metallurgy is steel, an iron-carbon alloy with wide applications in various industries, including shipbuilding, as it is one of the main materials in ship construction. Carbon in steel ranges from 0.02% to 0.14%, but to obtain the best-quality steel for shipbuilding, the carbon content should be 0.10-0.25%. Alloying is also important to improve the properties of steel.

Keywords: Chemistry, carbon, compounds, metallurgy, steel, alloying.

Introduction

The world is full of organic and inorganic chemical compounds formed by interactions among chemical elements found in nature. In various branches of industry, they are mainly guided by “applied chemistry”, which, based on the theories of “pure chemistry”, studies specific issues that have practical applications. Chemistry has played and will continue to play an important role in the development of science and technology, because it sometimes has a positive, sometimes a negative impact on the environment in which people live. People are always trying to counteract the negative chemical effects with chemical means.

Results and their judgment

In the Mendeleev periodic system, there are currently 1-118 elements (117 are missing), of which 94 elements exist naturally in the universe, and the rest are obtained artificially. Of the existing chemical elements, four are important: carbon, hydrogen, oxygen, and nitrogen, which together make up 99% of living organisms and are called the main elements of organic compounds. Other chemical elements also exist in living organisms, which have their own significance. There are also elements with toxic and radioactive properties in the periodic system.

Carbon Latin: Carboneum - in the Mendeleev periodic system, it is located in the second period and group IV A. Its international name is associated with the Latin word Carbo — carbon. The atomic number of carbon is 6, and the atomic mass is 12.011. It has 6 protons and 6 neutrons in its nucleus, and 6 electrons orbit it. Carbon-12 accounts for 99% of the carbon in nature. The remaining 1% is in the form of form carbon-13 (stable) and form carbon-14 (radioactive) isotopes.

Pure carbon occurs in nature in several forms, but the most important of them is graphite, which is soft, brittle, and flaky. Diamonds are also found, and they can be colorless or colored and are very hard. Amorphous carbon is also found in coal and soot. Carbon is abundant in nature in the form of coal. The price of carbon itself is very low, but the price of a natural diamond can be thousands and millions of dollars per gram. Carbon forms more than 20 million compounds and is the basis of life.

In the universe, carbon is formed as a result of thermonuclear reactions in the cores of stars. At this time, three helium-4 (He-4) nuclei fuse to form carbon, a symbol of life on Earth.

Carbon is a very important element found in both organic and inorganic compounds, but it is still considered the main element of organic compounds. Carbon can form strong bonds with other elements and form numerous strong organic compounds. Carbon forms a chain to which the main elements of organic compounds are connected: hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), phosphorus (P), and forms organic substances with these elements: proteins, fats, carbohydrates, amino acids, nucleic acids, etc.

Carbon is constantly circulating in the human body. A person receives about 300 mg of carbon per day with food and excretes it mainly as exhaled carbon dioxide (CO₂) and in urine. Carbon makes up about 21% of the human body, makes up 2/3 of the muscle mass, and 1/3 of the bones. Therefore, life is impossible without carbon, and carbon is the most important element of the living world.

The main mass of carbon is found in the form of compounds such as carbonates, oil, fuel, natural gas (up to 99% methane), peat, bitumen, etc. Carbon primarily forms

hydrocarbons - organic compounds, which are characterized by fairly strong covalent bonds.

Carbon is involved in the biological cycle occurring in nature. Carbon dioxide (CO_2) constantly circulates in nature. CO_2 is released into the atmosphere as a product of any combustion, from volcanic gases, hot mineral springs, from the upper layers of the seas and oceans, from the exhalation of living organisms, etc. However, carbon is also absorbed by plants, which then use it to produce organic substances. This cycle is constantly occurring in nature.

Carbon is characterized by many positive properties, given the compounds it forms, and it plays a major role in human life.

In the form of fossil fuels (coal, natural gas, oil), carbon is one of the main sources of energy. It is also used in medicine and pharmacology, particularly in the production of medicines. Carbon in its natural form - graphite is used in the production of pencils, and it is also used as a lubricant at extremely high or low temperatures. Graphite is characterized by a luster like that of a metal and is also a good conductor of electricity and heat.

Diamond is the hardest natural substance. Diamond and graphite are characterized by interconversion at high temperatures ($20000\text{ }^\circ\text{C}$) and high atmospheric pressures (11 -12 GPa). Diamond is used as an abrasive material due to its exceptional hardness. Diamond is hard because each carbon atom is connected to four other carbon atoms by strong covalent bonds, forming a strong three-dimensional lattice. In graphite, each carbon atom is connected to only three atoms, forming flat layers, and the bonds between the layers are weak. Therefore, it has a sheet-like structure. Diamond is one of the best thermal conductors, but it does not conduct electricity. Due to diamond's high thermal conductivity, it is considered a promising material for coating central processors in semiconductor technology. However, its use is limited by its high cost and processing difficulty. In recent years, significant developments have occurred in the field of superhard composite materials. However, the metal's thermal rigidity limits the use of metal-diamond materials under high loads. Superhard carbon composites can be produced by combining individual diamond grains with carbon, resulting in carbon atoms in various hybrid states. The synthesis is carried out from a mixture of individual carbon substances. The material developed in this way is called carbonyl-carbonium plus diamond. The study of carbon's properties has opened new possibilities for super-strong composite materials and the use of diamond in new technologies.

As mentioned, carbon forms a large number of chemical compounds, both organic and inorganic. Under ordinary conditions, carbon is chemically inert, but at high temperatures, it combines with many elements and exhibits strong reducing properties.

When heated, carbon reduces metals from metal oxides. Therefore, this property of it is widely used in metallurgy.

One of the products of metallurgy - an alloy - is steel, which has wide application in various branches of industry, especially in the construction industry and shipbuilding.

In modern shipbuilding, steel is one of the main structural materials. Steel is characterized by high strength, so large cargo ships and tankers are made of this material.

Steel is an iron-carbon alloy, with carbon content ranging from 0.02% to 2.14%. In modern technology, steel is considered one of the most important engineering materials. Steel is characterized by high strength, plasticity, and high ability to deform without breaking. It is characterized by heat resistance - it retains its properties at quite high temperatures, and it is characterized by good forging, welding, and forming. The melting point of steel is 1370-1500 °C. Medium thermal and electrical conductivities characterize it.

The widespread use of steel is also due to its relatively low cost and ease of large-scale production. In addition, it is possible to change the properties of steel by varying the iron-to-carbon ratio and using the resulting alloy for the appropriate purpose.

Iron and carbon form the chemical compound cementite (Fe_3C), which contains 6.67% carbon and is one of the components of steel. In iron-carbon alloys, carbon can exist in the form of cementite or free graphite, which is the lowest-strength phase in the alloy.

Depending on the iron-to-carbon ratio in steel, the melting point varies.

Table 1. Main melting temperature ranges

Material	Carbon %	Melting temperature
Pure iron	0 %	$\approx 1538^0 \text{ C}$
Low carbon steel	0,1 – 0,3 %	$\approx 1450 - 1520^0 \text{ C}$
Medium steel	0,3 – 0,6 %	$\approx 1400 - 1500^0 \text{ C}$
High carbon steel	0,6 – 1,0 %	$\approx 1350 - 1400^0 \text{ C}$

As shown in the table, the melting temperature decreases with increasing carbon content. This is because carbon disrupts the iron crystal lattice, causing melting to begin at a lower temperature.

The so-called liquidus line exists in the alloy when crystallization begins and accordingly varies with carbon content. At a temperature above the liquidus line, the alloy is liquid. Near the liquidus line, primary crystallization and phase transformation begin, after which a solid solution of carbon in the iron modification, called austenite,

is formed. As cooling proceeds, the solid phase increases, and the temperature at which the crystallization process ends is called the solidus line. Therefore, crystallization of the alloy occurs between the liquidus and solidus lines.

Table 2. Crystallization temperature ranges depending on carbon content

Carbon content %	Crystallization temperature ($\approx$) Liquidus line
0 %	$\approx 1538^0 \text{ C}$
0,2 %	$\approx 1500 - 1520^0 \text{ C}$
0,5 %	$\approx 1450 - 1500^0 \text{ C}$
1 %	$\approx 1400 - 1450^0 \text{ C}$
2 %	$\approx 1300 - 1400^0 \text{ C}$
4,3 % (eutectic)	$\approx 1147^0 \text{ C}$

As shown in the table, the crystallization temperature decreases with increasing carbon content in the alloy.

With decreasing temperature, the solubility of carbon in iron gradually decreases and, accordingly, the amount of carbon in the alloy increases. An alloy containing 4.3% carbon exhibits certain features.

- Like pure metals, its crystallization occurs at a constant temperature. The liquidus and solidus lines coincide.
- The crystallization temperature is minimal and is 11470°C .
- During the crystallization process, austenite and cementite crystals are simultaneously separated, and a micromechanical mixture is obtained, which is called ledeburite. Such an alloy is the only one in the iron-carbon system and is called a eutectic alloy.

According to its properties, austenite is characterized by high plasticity and high impact resistance.

Cementite is characterized by high hardness and high wear resistance, but is brittle and easily broken, not plastic. Cementite is an essential component of steel, as it increases its strength and hardness.

Table 3. The influence of carbon on the properties of steel

Carbon content %	Steel type	Hardness	Toughness	Plasticity Ductility	Weldability	Main use
0,02 – 0,10	Very low carbon	Low	Low	Very high	Very good	Thin sheet, wire
0,10 – 0,25	Low carbon	Medium	Average	High	Good	Structures, ships, pipes.
0,25 – 0,60	Medium carbon	High	Average high	Average	Average	Mechanical details, shafts
0,60 – 1,00	High carbon	Very High	High	Low	Bad	Springs, instruments
1,00 – 2,00	Very high carbon	Very High	Very high	Very low	Very bad	Cutting tools.

As mentioned, the carbon content in iron-carbon alloys has a significant effect, giving them special properties.

An alloy containing up to 0.02% carbon is called technical iron, and one containing up to 0.01% carbon is called ferrite.

As shown in the table, carbon has a significant effect on the alloy's properties. In particular, increasing carbon in steel increases strength and hardness but decreases plasticity (ductility) and weldability. It is also clear from the table that low-carbon steel is used in shipbuilding for structural applications, with a carbon content of 0.10-0.25%. It is worth noting that in addition to iron and carbon, steel contains permanent impurities - silicon, manganese, sulfur, and phosphorus. Each of them also has a specific effect on steel quality. Silicon protects steel from oxidative processes. Its amount in steel is within 0.15-0.3%. Increases strength and ductility but reduces plasticity. Manganese also protects steel from oxidation; it is a good oxidizer that increases the strength and ductility of steel. Its amount in steel is within the limits of 0.5-0.8%. The positive side of manganese in steel is that it significantly mitigates the negative effect of sulfur on steel properties. Sulfur and phosphorus are considered harmful impurities because they reduce steel quality. In order to improve the properties of steel, a purposeful change is made to the composition of the material. For this purpose, one or more chemical elements are added to the steel composition. Such steel is called alloy steel, and the chemical elements introduced into steel are called alloying elements. Alloying elements are mainly chromium (Cr), which increases corrosion resistance, strength, and wear resistance. Chromium is used in the production of stainless steel. Nickel (Ni) also increases corrosion resistance, plasticity, and strength. Vanadium (V) increases strength and wear resistance, and tungsten (W) increases strength at high temperatures and is used in high-speed steels. Other chemical elements

are also used for alloying: molybdenum (Mo), titanium (Ti), aluminum (Al), boron (B), -- which improve structural stability and density.

Given that ships must navigate in saltwater of varying concentrations, which is a major cause of corrosion, it is necessary to alloy the steel used in shipbuilding.

By increasing the carbon content of steel from 2.14% to 6.67%, cast iron is obtained, which is also a useful material in various industries. Cast iron is characterized by lower strength and ductility than steel. It is not plastic, brittle, or impact-resistant, so cast iron is not used under heavy loads. However, cast iron is also used in shipbuilding to make ship engines. Pump and valve housings can also be made from cast iron. Cast iron is relatively cheap to produce, is highly shrinkable, and allows complex parts to be easily cast. Studies have shown that the highest-quality cast iron is obtained when the carbon content in the iron-carbon alloy is 2.5-4.0%. Like steel, cast iron is alloyed with various alloying elements, which have unique positive effects on its properties.

Along with many positive properties, excess carbon in nature also has harmful effects. As mentioned, carbon is a symbol of life, but excess carbon also threatens it.

Carbon is a component of atmospheric air, which can have a significant impact on the climate. Carbon is present in the atmosphere mostly as soot, which results from vehicle exhaust and thermal power plant emissions, and is also released during open coal mining. All this has a serious impact on human health, especially by increasing the risk of lung and other respiratory diseases. Carbon C (14) is especially dangerous and toxic to the body because it causes a change in the chemical composition of the protein molecule. Carbon forms carbon dioxide (CO₂), which is formed in nature in various ways. The main source of carbon dioxide is the combustion of fuel, which is why its concentration in the atmosphere is increasing significantly. Carbon dioxide absorbs infrared radiation across various wavelengths, preventing heat from escaping from the Earth into space. This causes the air temperature on the Earth's surface to increase. The same property is characteristic of water vapor, methane, ozone, and other atmospheric gases. The heating of the air near the Earth's surface caused by atmospheric gases absorbing infrared radiation from the Earth is called the greenhouse effect, and these gases are called greenhouse gases. That is why carbon dioxide is considered the main cause of Earth's temperature increase.

In 1887, an additional international agreement was concluded within the framework of the UN Framework Convention on Climate Change, known as the Kyoto Protocol. Unlike the Convention, this protocol set limits on countries' greenhouse gas emissions, but it did not yield results; accordingly, greenhouse gas emissions are increasing. The increase in greenhouse gas emissions is directly linked to glacier

melting and global problems. Therefore, scientists have set a goal to reduce the amount of CO₂ in the atmosphere.

Among the compounds formed from carbon in nature, hydrocarbons are also notable, from which plastic and other polyethylene materials are produced. These materials are a serious problem for nature and the living world in general. Therefore, one of the main tasks today is to significantly reduce the production of plastic and polyethylene materials and replace them with other biodegradable materials, because plastic, when burned or biodegraded, releases harmful gases into the atmosphere, such as CO₂, CO, and CH₄. These gases have a significant negative impact on the human respiratory tract and cause serious health problems.

Based on all of the above, carbon is a very important chemical element in nature, with many aspects.

Conclusion

So, carbon is a chemical element without which life is impossible, because carbon forms such organic compounds as proteins, fats, carbohydrates, etc. These compounds are essential substances for all living organisms.

In addition, carbon forms oil and natural gas, which are the main sources of energy. Carbon compounds are used in medicine and pharmacology.

In nature, carbon occurs in the forms of diamond and graphite, which have distinct properties and are used for various purposes.

By adding carbon to diamond, it is possible to produce super-strong composite materials called carbal. The study of carbon's properties opened up new opportunities for its use in technology.

Carbon forms not only organic compounds, but also inorganic compounds. It is included in the composition of such a strong metal as steel. Steel is one of the most important engineering materials, widely used in construction and shipbuilding. Steel is an iron-carbon alloy, with carbon content ranging from 0.02% to 2.0%. With this ratio, steel exhibits the best properties.

Carbon forms CO₂, which constantly circulates in nature. Carbon dioxide (CO₂) is a very important compound. On the one hand, plants absorb it and use it to produce organic matter. On the other hand, CO₂ absorbs infrared radiation across various wavelengths, preventing heat from escaping from Earth into space and leading to an increase in Earth's temperature. Therefore, carbon dioxide is considered the main cause of Earth's temperature increase. Excess CO₂ is harmful to life.

Thus, along with many positive characteristics, carbon also has negative characteristics.

References:

1. CLAUDIO T> SUPURAN. GIUSEPPINA DE SIMONE. CARBONIC ANHYDRASES AS BIOCATALYSTS, From Theory to Medical and Industrial Applications, 2015 Amsterdam.
2. David A Porter, Kenneth E Eastering, and Mohamed Y. Sherif. Phase transformations in Metals and Alloys. 4th edition. 2022 GRC Press. USA Boca Raton. Florida.
3. Fred T, Mackenzie, Abraham, Rman. Carbon in the Geobiosphere: Earth's Outer Shell, 2006. Springer Dordrecht.
4. Juan m.d Tascon (Editor), Novel Carbon Adsorbents, 2012, Elsevier.
5. Kirk-Otmer Encyclopedia. 3 ed. vol 4. N-Y. 1973
6. Ljubisa R, Chemistry and Physics of Carbon, 2020 (Volume 30, 1st Edition), Routledge & CRC Press.
7. Ralph Setton, Patrick Bernier, Serge Lefrant. Carbon Molecules and Materials. 2002. CRC Press, London/New York (Routledge)
8. William D Callister Jr, David G. Rethwisch. Materials Science and Engineering: An Introduction, 10 th edition, 2018, Wiley. USA. New Jersey.
9. G. Kajaia. „Ecology,, Tbilisi,, 2022
- 10.G. Gunia. „Ecological Monitoring,, Tbilisi. 2019
- 11.E. Elizbarashvili, Organic Chemistry, Tbilisi. 2013
- 12.M. Okrosashvili, N. Kenchiashvili. Materials Science
- 13.Zh. Petriashvili, General Chemistry Lecture Course, Tbilisi. 2016

Content

Elida Kfivedelidze, Ekaterine Gvarishvili

THE PROBLEM OF OVERWEIGHT AND OBESITY AMONG GEORGIAN SAILORS5

Nino Tchilaia, Ekaterine Chikviani

THE IMPACT OF LOGISTICS ON BUSINESS PERFORMANCE10

Elida Kfivedelidze, Ekaterine Gvarishvili

COMPARATIVE ANALYSIS OF HEALTHCARE MANAGEMENT SYSTEMS: EXPERIENCE OF GEORGIA AND NEIGHBOURING COUNTRIES.....21

Imeda Pakhsadze, Iago Beridze, Givi Bakradze

DETERMINANTS OF STRUCTURAL CHANGE IN TRADE FLOWS.....51

Parmen Kfivedelidze, Dursun Tsintsadze, Giorgi Kikvidze, Valerian Imnaishvili, Nino Beridze

MODERN NAVIGATION SYSTEMS AND THEIR ROLE IN INCREASING THE SAFETY OF MARINE TRANSPORTATION.....60

Levan Gvarishvili, Mirza Sugnishvili, Giorgi Abashidze

PROBLEMS OF RELATIONS WITH THE EURASIAN ECONOMIC UNION.....86

Tamar Diasamidze, Tatia Tsetskhladze

BUSINESS COMMUNICATIONS AS A FORMULA FOR EFFECTIVE BUSINESS RELATIONS.....93

Maia Chechelashvili, George Gabedava, Tengiz Aphkhazava; Nino Tchilaia

PROSPECTS FOR REALIZING THE POTENTIAL OF THE EURASIAN ECONOMIC UNION IN THE SYSTEM OF INTERNATIONAL TRANSPORT CORRIDORS.....100

Nugzar Bolkvadze, Ruslan Verdzaдзе, Aram Bazaian, Levan Bolkvadze, George Gabedava

OPTIMIZING THE OPERATION OF SHIPS WITH THE USE OF ARTIFICIAL INTELLIGENCE SYSTEMS.....107

<i>Kakhaber Khintibidze, Vladimir Nemsadze, Levan Gobadze, David Botsvadze</i>	
STRATEGIES OF ENHANCING THE ENERGY EFFICIENCY OF SHIPS WITHIN THE FRAMEWORK OF GLOBAL DECARBONISATION.....	127
<i>Teimuraz Gograchadze; Taniel Pakşadze</i>	
LOGISTICS AS A SCIENTIFIC TOOL FOR MANAGING FLOW PROCESSES.....	145
<i>Valerian Imnaishvili</i>	
ANALYSIS OF DEATH AND INJURY CASES AMONG GEORGIAN SEAFARERS: MEDICO-LEGAL ASSESSMENT AND RECOMMENDATIONS.....	150
<i>Valerian Imnaishvili, Giorgi Kikvidze</i>	
IMPROVING THE INTERACTION BETWEEN SEAPORTS AND RAIL TRANSPORT.....	155
<i>Parmen Kfvedelidze, Dursun Tsintsadze</i>	
STRATEGIES FOR ENHANCING THE COMPETITIVENESS AND ATTRACTIVENESS OF GEORGIA’S BLACK SEA PORTS.....	162
<i>George Gabedava, Nino Tchilaia</i>	
THE ROLE OF PPP FOR A TRANSITION TO GREEN PRACTICES IN THE MARITIME INDUSTRY.....	168
<i>Tamila Ardemanashvili</i>	
CARBON AND ITS IMPORTANCE.....	180

FOR AUTHOR USE ONLY

FOR AUTHOR USE ONLY

**More
Books!**

yes
I want morebooks!

Buy your books fast and straightforward online - at one of world's fastest growing online book stores! Environmentally sound due to Print-on-Demand technologies.

Buy your books online at
www.morebooks.shop

Kaufen Sie Ihre Bücher schnell und unkompliziert online – auf einer der am schnellsten wachsenden Buchhandelsplattformen weltweit! Dank Print-On-Demand umwelt- und ressourcenschonend produziert.

Bücher schneller online kaufen
www.morebooks.shop



info@omniscryptum.com
www.omniscryptum.com

OMNIScriptum



FOR AUTHOR USE ONLY

FOR AUTHOR USE ONLY

FOR AUTHOR USE ONLY