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IMPLEMENTATION OF THE CONTAINER ON BARGE CONCEPT IN INLAND WATERWAYS AS A TOOL FOR SUSTAINABLE INTERMODAL LOGISTICS

Abstract. Inland waterway transport is an environmentally friendly mode of transport with high cargo capacity, but it remains underutilized in many European countries. The implementation of the Container on Barge (COB) concept allows the integration of inland waterway transport into intermodal logistics chains, increasing the efficiency of container transport while reducing environmental impacts. COB enables the movement of standardized containers along rivers with minimal transshipment, which shortens delivery times, reduces handling risks, and improves overall reliability. This paper provides a systematic analysis of COB, identifying its key economic, operational, and environmental benefits, as well as challenges for implementation in the Slovak Republic. The study examines how COB can reduce transport costs, decrease road congestion, and lower greenhouse gas emissions, contributing to more sustainable logistics solutions. In addition, COB has the potential to support regional development by creating logistics hubs, generating employment, and enhancing the competitiveness of local transport networks. In conclusion, the COB concept is presented as a promising tool for sustainable and efficient intermodal logistics, offering significant benefits for both environmental protection and economic performance while supporting the transition toward greener transport solutions in Central Europe.
Keywords: Inland Waterway Transport, Container on Barge, Intermodal Transport, Sustainable Logistics

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Introduction

Freight transport constitutes a fundamental component of modern economic systems and plays a decisive role in ensuring the continuous flow of goods between production sites, distribution centers, and final consumers. In highly industrialized economies, freight transport accounts for approximately 10–15 % of total gross domestic product when considering direct and indirect effects, including logistics services, infrastructure investment, and employment. The rapid expansion of global trade, accelerated by economic globalization and digitalization, has led to a substantial increase in freight volumes worldwide. According to the World Trade Organization, the global volume of merchandise trade increased more than threefold between 1990 and 2020, while containerized transport now represents over 80 % of global general cargo movements. This growth places significant pressure on transport systems and infrastructure, resulting in congestion, increased energy consumption, and rising emissions of greenhouse gases. (World Trade Organization, 2020; Wiegmans & Konings, 2023)

The increasing dominance of containerization has fundamentally transformed freight transport organization. Standardized ISO containers (20-foot and 40-foot units) have enabled seamless intermodal transport, reducing handling times, cargo damage, and transaction costs. However, the concentration of freight flows in road transport corridors has led to severe externalities. The European Environment Agency reports that transport is responsible for approximately 25 % of total greenhouse gas emissions in the European Union, with road freight transport being the largest contributor within this sector. These developments underline the urgent need to restructure freight transport systems toward more sustainable and energy-efficient modes. (European Environment Agency, 2022)

Within the European Union, road freight transport remains the dominant mode, accounting for approximately 75 % of inland freight transport performance measured in tonne-kilometers. Despite its high flexibility, door-to-door accessibility, and relatively low initial infrastructure requirements, road transport produces the highest share of carbon dioxide emissions, nitrogen oxides, and noise pollution among all inland transport modes. In Slovakia, this dominance is even more pronounced. According to the Ministry of Transport of the Slovak Republic, road transport accounts for more than 70 % of total freight transport volume, while its contribution to transport-related CO_2 emissions exceeds 85 %. This imbalance generates significant environmental burdens and accelerates the deterioration of road infrastructure, increasing public expenditure on maintenance and reconstruction. (Ministry of Transport of the Slovak Republic, 2019)

The negative impacts of excessive reliance on road freight transport are not limited to emissions alone. Road congestion in major European corridors results in productivity losses estimated at approximately 1 % of EU GDP annually. In Slovakia, congestion-related delays are most evident in the Bratislava metropolitan area and along international transit routes connecting Austria, Hungary, and the Czech Republic. These inefficiencies highlight the structural limitations of road transport as the sole backbone of freight logistics and strengthen the argument for a modal shift toward alternative transport modes. (European Commission, 2021)

Inland waterway transport is widely regarded as one of the most energy-efficient and environmentally friendly freight transport modes. Due to the physical properties of waterborne movement, vessels encounter significantly lower rolling resistance compared to road and rail vehicles, allowing the transport of large cargo volumes with relatively low fuel consumption. Empirical studies indicate that inland waterway transport requires approximately 0.3–0.4 MJ per tonne-kilometer, whereas road transport typically consumes between 1.2 and 1.8 MJ per tonne-kilometer. Despite these advantages, the potential of inland waterway transport remains underutilized in Central and Eastern Europe due to infrastructural deficits, hydrological constraints, and limited integration into intermodal logistics chains. (Šimko, 2018)

One of the most promising approaches to revitalizing inland waterway transport is the Container on Barge (COB) concept. COB represents a modern logistical solution that integrates inland waterway transport into intermodal container chains by enabling the transport of standardized containers between seaports and inland terminals using river vessels. This concept reduces the need for multiple transshipments, improves transport reliability, and significantly lowers the environmental footprint of freight transport. The relevance of COB is particularly high for landlocked countries such as Slovakia, which depend heavily on efficient connections to global maritime trade networks. (State Navigation Administration of the Slovak Republic, 2020)

From a historical and geopolitical perspective, inland waterway transport has always been closely linked to economic corridors and regional development. The Danube River, as Europe's second-longest river with a navigable length of approximately 2,400 km, connects ten countries and serves as a core transport axis within the Trans-European Transport Network (TEN-T). For Slovakia, the Danube represents the only direct inland waterway connection to major European seaports such as Rotterdam, Hamburg, and Constanța. European Union policy frameworks, including the White Paper on Transport (2011) and the Sustainable and Smart Mobility Strategy (2020), explicitly promote the shift of freight transport from road to rail and inland waterways as a key instrument for achieving climate neutrality by 2050. (European Commission, 2011; European Commission, 2021; Ministry of Transport of the Slovak Republic, 2019)

1. Methodology

The methodological framework of this paper is based on a systematic literature review combined with qualitative and comparative analysis. The literature review includes peer-reviewed scientific articles indexed in international databases such as Scopus and Web of Science, policy documents issued by European Union institutions, and official reports from Slovak authorities responsible for inland navigation and transport infrastructure. Priority was given to sources with high academic relevance, citation frequency, and direct applicability to inland waterway transport and intermodal logistics. (Ministry of Transport of the Slovak Republic, 2019)

The analytical component of the study relies on the synthesis of existing knowledge and empirical findings related to the Container on Barge concept. This synthesis includes the evaluation of operational characteristics, economic performance indicators, and environmental impacts of COB systems implemented in Western European countries such as Germany, the Netherlands, and Belgium. Comparative analysis was applied to identify key success factors and constraints affecting COB performance and to assess their transferability to Slovak conditions. (Wiegmans, Konings, 2023)

Quantitative data used in the analysis include transport performance indicators (tonne-kilometers, TEU volumes), emission factors (g CO_2/tkm), and cost parameters (€/tkm) derived from European statistical sources and national transport reports. Where direct Slovak data were unavailable, benchmark values from comparable EU regions were used and critically assessed in relation to local conditions. This approach ensures methodological robustness while acknowledging data limitations. (European Commission, 2022)

The methodological design reflects an interdisciplinary research approach, integrating perspectives from logistics management, transport economics, environmental sustainability, and transport policy analysis. Such an approach is characteristic of doctoral-level research, as it enables a comprehensive evaluation of complex transport systems and supports the identification of research gaps related to the long-term sustainability of freight transport. (Konings, Priemus, 2008)

2. Inland Water Transport and Its Importance in Logistics

Inland waterway transport represents one of the oldest yet still highly relevant modes of freight transport, particularly in regions with developed river networks. Within the European Union, the total length of navigable inland waterways exceeds 42,000 kilometers, connecting major industrial regions, metropolitan areas, and seaports. These waterways form a dense network that enables the transport of bulk goods, containers, and project cargo across long distances with relatively low energy inputs. Despite this extensive network, inland waterway transport currently accounts for only about 6 % of total inland freight transport performance in the EU, indicating a significant untapped potential for modal shift. (Šimko, 2018)

From a logistics perspective, inland waterway transport offers high capacity and reliability for the movement of large freight volumes. A single river barge convoy can replace between 80 and 150 heavy-duty trucks, depending on vessel configuration and waterway conditions. In terms of transport performance, a standard inland container vessel can carry between 200 and 400 TEU, while push convoys on major rivers such as the Rhine can exceed 500 TEU. These capacity advantages make inland waterway transport particularly suitable for high-volume and medium- to long-distance freight flows. (Wiegmans, Konings, 2023)

The strategic role of inland waterway transport in logistics systems is closely linked to its integration into intermodal transport chains. Inland waterways often function as feeders to major seaports, facilitating the distribution of containers to inland logistics hubs. In Western Europe, particularly along the Rhine–Scheldt corridor, inland shipping handles more than 35 % of container hinterland traffic from major ports such as Rotterdam and Antwerp. This integration significantly reduces congestion in port areas and on surrounding road networks. (European Commission, 2022)

In Central and Eastern Europe, the role of inland waterway transport is comparatively weaker, mainly due to historical underinvestment and limited intermodal integration. Nevertheless, rivers such as the Danube offer substantial opportunities for improving freight logistics performance. The Danube corridor connects the North Sea ports via the Rhine–Main–Danube Canal with the Black Sea and serves as a key east–west transport axis. For Slovakia, which has approximately 172 kilometers of navigable waterways, the Danube represents a strategic asset for enhancing logistics connectivity. (State Navigation Administration of the Slovak Republic, 2020)

2.1 Environmental and Energy Characteristics

One of the most significant advantages of inland waterway transport is its superior energy efficiency. Due to low hydrodynamic resistance, vessels require considerably less propulsion energy per transported unit than road or rail vehicles. Empirical studies indicate that inland shipping consumes on average 0.3–0.4 MJ per tonne-kilometer, compared to approximately 0.6–0.8 MJ per tonne-kilometer for rail transport and 1.2–1.8 MJ per tonne-kilometer for road transport. This difference translates directly into lower fuel consumption and reduced operating costs. (Šimko, 2018)

The energy efficiency of inland waterway transport is closely reflected in its emission performance. Average carbon dioxide emissions from inland shipping amount to approximately 30–35 g CO_2 per tonne-kilometer, whereas road freight transport emits between 90 and 120 g CO_2 per tonne-kilometer. Rail transport typically falls between these two modes, with emissions of approximately 45–60 g CO_2 per tonne-kilometer, depending on the energy mix used for traction. These values highlight the substantial potential of inland waterway transport to contribute to climate change mitigation. (European Environment Agency, 2022)

Beyond greenhouse gas emissions, inland waterway transport also demonstrates advantages in terms of local environmental impacts. Emissions of nitrogen oxides (NO_x) and particulate matter (PM) per tonne-kilometer are significantly lower than those of heavy-duty road vehicles. Additionally, noise emissions generated by inland vessels are considerably lower, particularly in urban and peri-urban areas. Studies have shown that noise levels from river shipping are typically 10–15 dB lower than those generated by road freight traffic, contributing to improved quality of life for residents along transport corridors. (Zhang et al., 2022)

In terms of infrastructure sustainability, inland waterway transport causes minimal physical damage to transport infrastructure compared to road transport. While heavy trucks exert high axle loads that accelerate pavement degradation, waterborne transport distributes loads more evenly across water surfaces. As a result, the lifecycle costs of inland waterways are generally lower than those of road networks. This characteristic is particularly relevant for public budgets, as maintenance costs for inland waterways are estimated to be 3–5 times lower per tonne-kilometer than for road infrastructure. (European Commission, 2021)

2.2 Role in Domestic and International Intermodal Systems

In modern logistics systems, inland waterway transport plays a crucial role as an integrative element within intermodal transport chains. By connecting seaports with inland terminals, it enables efficient distribution of containers to hinterland regions while reducing reliance on road transport. In the Rhine corridor, for example, inland waterway transport handles more than 2 million TEU annually between Rotterdam and inland ports such as Duisburg, Mannheim, and Basel. This model has become a benchmark for sustainable hinterland logistics in Europe. (Wiegmans, Konings, 2023)

The economic benefits of integrating inland waterway transport into intermodal systems are substantial. Inland shipping offers lower transport costs per tonne-kilometer, particularly for distances exceeding 300 kilometers. Cost comparisons indicate that inland waterway transport can be 30–50 % cheaper than road transport for bulk and containerized cargo over medium and long distances. Additionally, reduced handling frequency in intermodal chains lowers the risk of cargo damage and associated insurance costs. (Konings, Priemus, 2008)

In domestic logistics systems, inland waterway transport can also support regional distribution networks. Inland terminals often serve as logistics nodes that combine storage, value-added services, and intermodal transfer functions. This multifunctional role enhances supply chain resilience and flexibility. In countries such as Germany and the Netherlands, inland ports generate significant regional economic effects, including employment creation and industrial clustering. (OECD, 2020)

In Slovakia, the integration of inland waterway transport into intermodal systems remains limited. Although the Danube provides a direct connection to major European transport corridors, the utilization rate of Slovak inland ports is relatively low. Annual container throughput at Slovak river ports remains below 100,000 TEU, compared to several million TEU handled by major inland ports along the Rhine. This disparity underscores the need for targeted investments in terminal infrastructure and intermodal connectivity. (Slovak Shipping and Ports of the Slovak Republic, 2021)

Hydrological conditions also influence the reliability of inland waterway transport in Slovakia. Seasonal water level fluctuations on the Danube can restrict vessel draft and reduce carrying capacity, particularly during prolonged low-water periods. These constraints necessitate adaptive logistics planning and investment in waterway maintenance and flow regulation to ensure year-round navigability. (State Navigation Administration of the Slovak Republic, 2020)

Table 1. Comparison of Inland Waterway Transport Indicators: Slovak Republic vs. European Union

Indicator	Slovak republic	European Union (average)	Interpretation of difference
Share of road transport in freight transport	> 70 %	~75 %	Slovakia has a very strong dominance of road transport
Share of inland waterway transport	< 2 %	~6 %	Slovakia significantly lags behind the EU average
Length of navigable waterways	~172 km	> 42,000 km	Slovakia has a limited but strategic network
TEN-T status	Core corridor (Danube)	Core network	Slovakia has a full TEN-T status
Annual container volume (inland ports)	< 100,000 TEU	> 5 million TEU	Very low integration of Slovakia into container flows
Energy efficiency of IWT	0.3–0.4 MJ/tkm	0.3–0.4 MJ/tkm	Technically comparable conditions
CO_2 emissions from road transport	> 85 % of transport emissions	~77 %	Higher environmental pressure in Slovakia
Capacity reduction during low water	30–40 %	20–30 %	Higher hydrological risk in Slovakia
Level of terminal infrastructure	Low–medium	Medium–high	Key barrier for COB development
Use of COB in practice	Pilot / minimal	Common practice	High development potential for Slovakia
Potential CO_2 reduction using COB	5–7 %	10–15 %	Lower but still significant effect in Slovakia

3. The Container on Barge Concept

The Container on Barge (COB) concept represents a specialized form of inland waterway transport focused on the movement of standardized ISO containers using river vessels as part of intermodal logistics chains. The concept emerged in Western Europe during the late 20th century as a response to increasing congestion at seaports and on hinterland road corridors. Today, COB plays a crucial role in the hinterland distribution systems of major European ports, particularly along the Rhine–Scheldt and Seine corridors. Its importance is reflected in the fact that more than 35 % of all hinterland container flows from the Port of Rotterdam are currently transported by inland vessels. (Konings, Priemus, 2008)

The fundamental objective of the COB concept is to shift container flows from road transport to inland waterways while maintaining high levels of reliability, safety, and cost efficiency. By integrating river transport into door-to-door logistics chains, COB contributes to reducing external transport costs such as emissions, noise, congestion, and accidents. These benefits are particularly relevant in densely populated regions and along major European freight corridors, where transport externalities pose significant societal challenges. (Wiegmans, Konings, 2023)

COB is especially suitable for landlocked countries with access to navigable rivers, as it provides an efficient connection to global maritime trade without the need for extensive rail or road infrastructure expansion. For Slovakia, the COB concept offers a strategic opportunity to enhance its integration into European logistics networks by utilizing the Danube as a high-capacity transport corridor connecting inland terminals with seaports such as Rotterdam, Hamburg, and Constanța. (State Navigation Administration of the Slovak Republic, 2020)

3.1 COB Operating Principle

The operational principle of the COB system is based on the use of standardized ISO containers, primarily 20-foot (TEU) and 40-foot (FEU) units, which are directly loaded onto inland waterway vessels at seaports or inland terminals. These containers are transported along rivers to inland ports, where they are transferred to road or rail vehicles for final delivery. This process minimizes the number of handling operations, thereby reducing transit times, handling costs, and the risk of cargo damage. (Wiegmans, Konings, 2023)

In technical terms, COB operations rely on specialized inland container vessels and barges designed to carry containers in multiple layers. Modern inland container vessels typically have a length of 110–135 meters, a beam of 11.4 meters, and a carrying capacity ranging from 200 to 400 TEU, depending on waterway class and vessel draft. On major waterways such as the Rhine, push convoys consisting of several barges can transport more than 500 TEU in a single voyage. (European Commission, 2021)

An important feature of the COB concept is vessel flexibility. Modular barge systems allow operators to adjust vessel size and capacity according to cargo volumes and hydrological conditions. This flexibility is particularly important during periods of low water levels, when vessel draft must be reduced. In such cases, operators may increase the number of barge units or adjust loading strategies to maintain transport continuity. (Zhang et al., 2022)

The integration of COB into port operations is facilitated by specialized container terminals equipped with gantry cranes or mobile harbor cranes. Handling productivity at inland terminals typically ranges between 20 and 30 container moves per hour, which is comparable to smaller seaport terminals. Advanced terminal management systems further enhance operational efficiency by optimizing vessel schedules, yard operations, and intermodal transfers. (OECD, 2020)

3.2 Economic Benefits

The economic benefits of the COB concept are multifaceted and occur at both the microeconomic and macroeconomic levels. At the operational level, inland waterway transport offers significantly lower transport costs per tonne-kilometer compared to road transport, particularly for medium and long distances. Empirical cost analyses indicate that inland shipping costs typically range between 0.02 and 0.04 EUR per tonne-kilometer, whereas road transport costs often exceed 0.06–0.10 EUR per tonne-kilometer for comparable distances. (Wiegmans, Konings, 2023)

One of the primary cost advantages of COB arises from economies of scale. By transporting large volumes of containers in a single voyage, inland vessels achieve lower unit costs than road vehicles, which are constrained by payload and driver working time regulations. For distances exceeding 300 kilometers, COB is often 30–50 % cheaper than road transport, particularly when external costs are internalized. (Konings, Priemus, 2008)

In addition to direct transport cost savings, COB generates indirect economic benefits by reducing congestion on road networks. The removal of heavy trucks from congested corridors leads to lower travel time variability and improved reliability for remaining road users. Studies estimate that each container shifted from road to inland waterway transport reduces congestion-related costs by approximately 30–50 EUR per trip in heavily trafficked regions. (European Commission, 2021)

COB also contributes to lower infrastructure maintenance costs. Heavy-duty vehicles are responsible for a disproportionate share of road wear, with a single truck causing damage equivalent to several thousand passenger cars. By shifting container flows to waterways, public authorities can reduce road maintenance expenditures and reallocate resources to other infrastructure priorities. (European Commission, 2021)

Empirical evidence from Western Europe confirms the economic viability of COB. In regions along the Rhine corridor, the introduction of COB services has reduced total logistics costs by 15–20 % for containerized freight over medium and long distances. These cost reductions have enhanced the competitiveness of inland ports and strengthened their role as logistics hubs. (Wiegmans, Konings, 2023)

3.3 Environmental Benefits

From an environmental perspective, the COB concept offers substantial advantages over road-based container transport. By utilizing energy-efficient inland vessels, COB significantly reduces greenhouse gas emissions per transported unit. On average, COB operations emit approximately 30–35 g CO_2 per tonne-kilometer, compared to 90–120 g CO_2 per tonne-kilometer for road transport. This represents a potential emission reduction of up to 70 % for containerized freight. (Šimko, 2018)

In addition to carbon dioxide, COB contributes to lower emissions of nitrogen oxides (NO_x) and particulate matter (PM), which are major contributors to air pollution and adverse health effects. Inland vessels equipped with modern engines and exhaust after-treatment systems can achieve NO_x emission reductions of up to 80 % compared to older road vehicle fleets. These improvements are particularly relevant in urban areas and along densely populated transport corridors. (European Environment Agency, 2022)

Noise reduction is another important environmental benefit of COB. Road freight transport generates high noise levels, especially during nighttime operations. Inland waterway transport produces significantly lower noise emissions, contributing to improved living conditions for residents near transport corridors. Noise measurements indicate that inland shipping reduces noise exposure by 10–15 dB compared to equivalent road freight traffic. (Zhang et al., 2022)

By reducing pressure on road infrastructure, COB also has long-term environmental benefits related to land use and resource consumption. Fewer road expansions and maintenance works translate into lower material consumption, reduced land take, and diminished disruption of natural habitats. These indirect environmental effects further strengthen the sustainability profile of the COB concept. (OECD, 2020)

3.4 Implementation Barriers

Despite its numerous advantages, the implementation of the COB concept faces several significant barriers. One of the most critical challenges is hydrological variability, particularly fluctuations in water levels that can restrict vessel draft and reduce carrying capacity. On the Danube, low-water periods can reduce vessel capacity by up to 30–40 %, affecting transport reliability and economic performance. (State Navigation Administration of the Slovak Republic, 2020)

Another major barrier is insufficient terminal and port infrastructure. Many inland ports in Central and Eastern Europe lack modern container handling equipment and adequate intermodal connections. In Slovakia, limited terminal capacity and outdated infrastructure constrain the integration of inland shipping into international container flows. (Slovak Shipping and Ports of the Slovak Republic, 2021)

Legislative and administrative barriers also hinder COB development. Differences in safety standards, certification procedures, and customs regulations across countries increase administrative complexity and costs for operators. Although EU harmonization efforts are ongoing, regulatory fragmentation remains a significant obstacle, particularly for cross-border inland shipping services. (Ministry of Transport of the Slovak Republic, 2019)

Finally, limited awareness and experience with COB among logistics operators in Central Europe impede market development. Many shippers perceive inland waterway transport as slow or unreliable, despite evidence to the contrary. Overcoming these perception barriers requires targeted information campaigns, pilot projects, and demonstration initiatives. (Wiegmans, Konings, 2023)

4. Discussion: COB Application in the Slovak Republic

The Slovak Republic possesses a strategically important inland waterway network, primarily represented by the Danube River, which forms part of the core Trans-European Transport Network (TEN-T). The Slovak section of the Danube, with a navigable length of approximately 172 kilometers, provides direct access to major European inland and maritime ports via the Rhine–Main–Danube corridor. This strategic position offers significant potential for the application of the Container on Barge (COB) concept as an integral component of intermodal freight transport systems. (State Navigation Administration of the Slovak Republic, 2020)

Despite its favorable geographical position, Slovakia currently underutilizes its inland waterway potential. Inland waterway transport accounts for less than 2 % of total freight transport performance in the country, which is substantially below the EU average of approximately 6 %. Annual container throughput at Slovak inland ports remains below 100,000 TEU, indicating limited integration into international container flows. This situation reflects structural weaknesses in infrastructure, logistics organization, and policy support. (Ministry of Transport of the Slovak Republic, 2019)

The application of the COB concept in Slovakia could significantly enhance the role of inland waterways in national and international logistics chains. By establishing regular container barge services between Slovak ports and major European logistics hubs, Slovakia could reduce its dependence on road transport for long-distance freight movements. This shift would contribute to improved transport efficiency, reduced environmental impacts, and increased resilience of supply chains. (Wiegmans, Konings, 2023)

4.1 Strategic Importance and Development Potential

The Danube River represents a key strategic asset for Slovakia's transport and logistics system. As a core TEN-T corridor, it connects Slovakia to major economic regions in Western and Southeastern Europe. Through the Rhine–Main–Danube Canal, Slovak inland ports gain access to North Sea ports such as Rotterdam and Hamburg, while downstream connections provide links to the Black Sea port of Constanța. This dual orientation significantly enhances Slovakia's logistics connectivity. (European Commission, 2021)

The development of COB services along the Danube could strengthen Slovakia's position as a logistics transit and distribution hub in Central Europe. Inland ports such as Bratislava and Komárno have the potential to serve as intermodal nodes linking river transport with road and rail networks. Modernization of these ports could enable the handling of larger container volumes and support the establishment of regular barge services. (Slovak Shipping and Ports of the Slovak Republic, 2021)

COB development also has positive implications for regional economic growth. Inland ports often function as catalysts for industrial clustering, attracting logistics service providers, manufacturers, and distribution centers. Empirical evidence from Germany and the Netherlands demonstrates that investments in inland port infrastructure can generate significant multiplier effects, including job creation, increased regional GDP, and enhanced competitiveness of surrounding regions. (OECD, 2020)

For Slovakia, the establishment of logistics centers along the Danube could support balanced regional development, particularly in regions with limited access to high-capacity transport infrastructure. By integrating COB into national logistics strategies, Slovakia could stimulate economic activity in river-adjacent areas and reduce regional disparities. (Wiegmans, Konings, 2023)

4.2 Barriers and Solutions for Slovakia

The implementation of the COB concept in Slovakia is constrained by several interrelated barriers. One of the most significant challenges is insufficient port and terminal capacity. Many Slovak inland ports lack modern container handling equipment, adequate storage areas, and efficient intermodal connections. As a result, their operational efficiency and attractiveness to logistics operators remain limited. (Slovak Shipping and Ports of the Slovak Republic, 2021)

Hydrological variability represents another critical constraint. Seasonal fluctuations in water levels on the Danube can affect navigability and vessel loading capacity. During prolonged low-water periods, vessel draft restrictions can reduce carrying capacity by up to 40 %, negatively impacting transport reliability and economic performance. Addressing this issue requires investment in riverbed maintenance, flow regulation, and adaptive vessel design. (State Navigation Administration of the Slovak Republic, 2020)

Administrative and legislative barriers further complicate COB implementation. Differences in regulatory frameworks, customs procedures, and safety standards across countries increase transaction costs for inland shipping operators. Although EU harmonization efforts have improved regulatory coherence, national-level administrative procedures remain complex and time-consuming. Simplification and digitalization of administrative processes are therefore essential to facilitate cross-border COB operations. (Ministry of Transport of the Slovak Republic, 2019)

A viable solution to these challenges lies in the development of a comprehensive national inland waterway strategy supported by public–private partnerships (PPP). PPP models enable the mobilization of private capital for port modernization and fleet renewal while ensuring public oversight and strategic alignment with national transport objectives. Such approaches have been successfully implemented in Western Europe and could be adapted to Slovak conditions. (European Commission, 2021)

4.3 Contribution to Sustainable Logistics

The adoption of the COB concept in Slovakia would contribute significantly to the development of sustainable logistics systems. By shifting container flows from road transport to inland waterways, COB reduces greenhouse gas emissions, air pollution, and noise, thereby supporting national and EU climate objectives. Model calculations suggest that transferring 10 % of long-distance container freight from road to inland waterways could reduce CO_2 emissions from freight transport in Slovakia by approximately 5–7 %. (Šimko, 2018)

COB also enhances the efficiency and resilience of intermodal logistics chains. Inland shipping provides an additional transport option that can complement road and rail modes, reducing vulnerability to congestion, infrastructure disruptions, and capacity constraints. This multimodal flexibility is increasingly important in the context of growing freight volumes and climate-related risks. (Zhang et al., 2022)

Furthermore, COB can support environmentally friendly distribution systems within inland logistics centers and industrial zones. By integrating river transport with last-mile road or rail distribution, Slovakia could reduce the environmental footprint of freight transport in urban and industrial areas. This approach aligns with the principles of sustainable urban logistics and green supply chain management. (OECD, 2020)

Conclusion

The analysis of the Container on Barge (COB) concept confirms that inland waterway transport represents a highly effective tool for enhancing the environmental, economic, and operational sustainability of freight transport systems. Compared to road transport, inland shipping offers significantly lower energy consumption, reduced greenhouse gas emissions, and higher transport capacity per unit. The COB concept further amplifies these advantages by enabling the seamless integration of inland waterways into intermodal container logistics chains, thereby addressing key inefficiencies associated with road-dominated freight transport.

From an environmental perspective, the findings demonstrate that COB can contribute substantially to emission reduction targets. The shift of container flows from road to inland waterways can reduce CO_2 emissions by up to 70 % per tonne-kilometer, alongside significant reductions in NO_x and particulate matter emissions. These effects are particularly relevant for countries such as Slovakia, where road freight transport dominates and environmental pressures from transport are increasing. The adoption of COB thus aligns closely with European Union climate and sustainability objectives, including the goal of climate neutrality by 2050.

Economically, the COB concept offers competitive advantages through lower transport costs, economies of scale, and reduced external costs. Empirical evidence from Western European countries indicates that the introduction of COB services can reduce total logistics costs by approximately 15–20 % for medium- and long-distance container transport. In addition, indirect economic benefits arise from reduced congestion, lower road infrastructure maintenance costs, and improved reliability of freight transport systems. These factors enhance the overall competitiveness of national logistics sectors.

In the context of the Slovak Republic, the Danube River constitutes a strategically valuable asset that remains underutilized. Despite its inclusion in the TEN-T core network, inland waterway transport accounts for only a marginal share of freight transport performance in Slovakia. The implementation of the COB concept could significantly improve Slovakia's integration into European and global logistics networks by strengthening connections to major seaports and inland logistics hubs. This would reduce dependence on road transport and increase the resilience of supply chains.

However, the successful implementation of COB in Slovakia requires addressing several structural barriers. These include insufficient port and terminal infrastructure, hydrological variability affecting navigability, and administrative and legislative complexities. Overcoming these challenges necessitates coordinated action by public authorities, private operators, and international partners. Strategic investments in port modernization, river infrastructure maintenance, and digitalization of administrative procedures are essential preconditions for the effective deployment of COB services.

Public–private partnerships (PPP) emerge as a particularly suitable financing and governance mechanism for inland waterway development. PPP models can facilitate the mobilization of private investment while ensuring alignment with national transport and sustainability objectives. Experiences from Western Europe demonstrate that PPP-based port and terminal development can accelerate infrastructure modernization and enhance operational efficiency. Adapting these models to Slovak conditions could significantly support the long-term viability of COB implementation.

From a logistics systems perspective, COB enhances intermodal integration and supply chain resilience. By providing an alternative transport mode for long-distance container flows, inland waterway transport reduces vulnerability to road congestion, infrastructure disruptions, and capacity constraints. This multimodal flexibility is increasingly important in the context of growing freight volumes, climate change impacts, and evolving trade patterns.

Based on the findings of this study, several key recommendations for Slovakia can be formulated. First, targeted investments in the modernization of inland ports and terminals along the Danube are necessary to increase handling capacity and intermodal connectivity. Second, legislative and administrative procedures related to inland navigation should be harmonized with EU standards and further simplified. Third, cooperation between public authorities, logistics operators, and port stakeholders should be strengthened to promote market acceptance of COB services. Finally, systematic monitoring and evaluation of environmental benefits should be implemented to quantify emission reductions and support evidence-based policymaking.

Future research should focus on several critical areas. These include the detailed quantification of economic impacts of COB at national and regional levels, assessment of COB adaptability to climate change and hydrological risks, and evaluation of the integration of COB into broader European intermodal networks. Further empirical research based on pilot projects and real-world operational data would provide valuable insights into the long-term performance and scalability of the COB concept in Central and Eastern Europe.

In conclusion, the implementation of the Container on Barge concept represents a viable and strategically important pathway toward sustainable freight transport in Slovakia and the wider Central European region. By leveraging its inland waterway potential, Slovakia can reduce the environmental burden of freight transport, enhance logistics efficiency, support regional economic development, and contribute to the achievement of European sustainability goals.

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