“Silk Way” – Maritime Logistics

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Abstract. This paper examines the role of transport corridors in Azerbaijan’s economic integration and evaluates options to increase the efficiency of ferry-based intermodal flows along the Caspian segment of the “Silk Way.” Particular attention is given to the strategic relevance of expanding corridor capacity, including the prospective operationalization of the Zangezur corridor referenced in the 10 November 2020 declaration (Clause 9), as a key regional connectivity objective. The study aims to justify a stepwise approach to improving wagon–container logistics and to quantify the potential productivity gains for Ro-Pax ferries. The methodology combines a review of logistics concepts and sources with an operational analysis of current rail–ferry practices, focusing on payload losses and cycle-time penalties associated with transporting rail wagons that carry “zero” cargo weight and generate inefficient cyclic (time) losses at terminals. A comparative assessment of alternative loading schemes shows that replacing wagon-based transport with direct container carriage and designing an optimized cargo plan aligned with modern logistics technologies can significantly increase the share of commercial cargo and reduce turnaround losses. Under the considered operating assumptions, the productivity of Ro-Pax vessels can be increased by up to four times, supporting higher throughput on emerging corridors.

Keywords: maritime transport, door-to-door delivery, just-in-time, logistics, transport technology, railway wagons, containers.

1 Introduction

Transport has become a fundamental component of modern society, enabling the physical movement of people and goods. While modern communication technologies allow access to remote regions of the world virtually, transport systems create an “effective space” that ensures the physical accessibility and efficient utilization of resources.

From this perspective, transport represents a key element of economic activity, facilitating the exchange of material goods and services. Efficient transport systems enable the movement of passengers and cargo from the point of origin to the final destination, commonly defined as “door-to-door” delivery.

In practice, transport operations can be categorized into five main modes: maritime, railway, road, air, and pipeline transport [1,2]. The integration of these modes forms the basis of modern logistics systems and supply chain efficiency.

1.1 Problem Statement

In practice, none of the major transport modes (with limited exception of road transport) is capable of independently providing full “door-to-door” delivery. Efficient transport operations therefore require the integration of multiple transport modes supported by advanced logistics and technological coordination.

Effective transportation systems depend on:

- high-level coordination between transport modes
- optimized logistics and technological infrastructure
- precise execution of operations

The organization of multimodal transport systems is inherently complex and must rely on scientifically grounded logistics frameworks supported by technological advancements. Such integration significantly enhances transport efficiency and contributes to broader socio-economic development.

Historical and contemporary trends demonstrate that the development of any state—physical, economic, political, and technological—is strongly dependent on the level of transport system development. The strategic importance of transport infrastructure in global integration has been demonstrated through large-scale international initiatives such as TRACECA, promoted during the presidency of Heydar Aliyev, played a significant role in the development of regional transport corridors.

The historical Silk Road, which passed through the territory of Azerbaijan, represents one of the earliest examples of intercontinental logistics integration. As illustrated in Fig. 1, the main land route of the ancient Silk Road extended across Eurasia, connecting key regions through a predominantly overland network.

Modern initiatives aimed at restoring and developing Silk Road corridors highlight the importance of efficient transport connectivity between Asia and Europe.

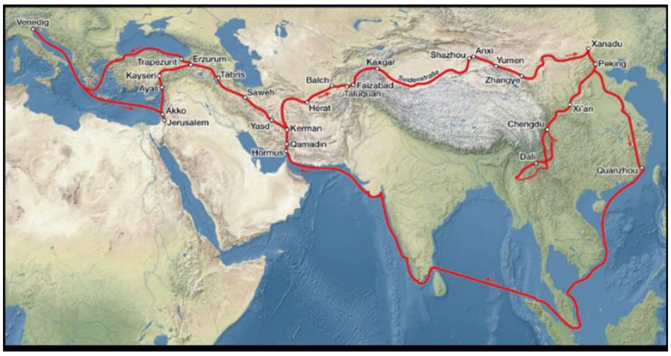

Fig. 1. The Silk Road, predominantly developed as a land-based route.

In this context, the development of new transport corridors, including the Zangezur corridor, plays a critical role in enhancing regional and global logistics systems. The introduction of additional east–west transport routes improve network resilience, reduces dependency on limited corridors, and increases overall transport efficiency.

The Caspian region, particularly through the Baku (Alat) port, is positioned as a key logistics hub enabling multimodal connections between Asia and Europe. The integration of maritime transport across the Caspian Sea with land corridors creates opportunities for direct and efficient cargo flows.

Therefore, the development and optimization of transport corridors should be considered a priority task for improving logistics performance, ensuring reliability, and enhancing economic integration at both regional and global levels.

From a conceptual standpoint, the Zangezur corridor should not be treated merely as an intermediate route within the transport network. Instead, it is proposed to define it as an "optimal corridor", reflecting its strategic efficiency, connectivity potential, and role in enhancing overall logistics performance.

2 Main Part

Modern transport systems are governed by two fundamental principles: ensuring a complete transportation cycle based on "door-to-door" delivery and maintaining "just-in-time" performance. The development of the Zangezur corridor contributes to reducing transport distances, minimizing auxiliary operations, simplifying transit procedures, and decreasing labor and time consumption. As a result, overall transport efficiency is improved, while logistics costs and delivery times are reduced [1,2,3].

Historically, economic interactions between regions originated in ancient trade systems. Early transport networks were represented by caravan routes and primitive land-based logistics systems, where goods were transported under challenging environmental and operational conditions (Fig. 2).

Fig. 2. Early trade and transport systems.

These early transport systems were associated with significant risks, including environmental hazards, piracy, and cargo loss. To mitigate these risks, various protective measures were developed, such as packaging, storage solutions, and cargo handling techniques. Although these approaches were limited in efficiency, they formed the foundation for the evolution of structured logistics systems and transport corridors.

Over time, these developments established requirements for safe, reliable, and efficient cargo circulation, storage, and distribution. This led to the emergence of optimized transport corridors, advanced cargo handling technologies, and the principles of cargo consolidation and containerization.

It is important to emphasize that containerization itself is not the final objective, but rather a tool for improving logistics efficiency. Continuous technological and operational improvements in container transport reduce time losses, labor intensity, and inefficient cargo turnover, thereby increasing transport productivity and commercial cargo volumes [1,2,3,4].

Based on these considerations, the authors propose a definition of "transport technologies" as a scientific discipline that studies and solves practical problems related to the physical movement of people and goods through the integrated use of transport systems, tools, methods, and scientific knowledge, ensuring efficiency, safety, reliability, and optimized operational sequences. Although this definition has not yet been widely adopted, no alternative comprehensive formulation has been proposed [5].

To further clarify the concept of logistics as a form of technological advancement, it is useful to consider its historical origins. The term "logistics" is derived from ancient Greek concepts related to reasoning, calculation, and planning.

In modern interpretation, logistics can be defined as a system for managing flows of goods, information, and financial resources in order to meet customer requirements in terms of quantity, quality, time, and cost. From this perspective, logistics is fundamentally linked to the efficient organization of transport processes and resource allocation.

The question of when logistics emerged as a structured discipline remains open. While formal recognition of logistics as a profession is often associated with the VII–IX centuries, its conceptual foundations can be traced back to much earlier forms of organized resource management [1,6].

Our research shows that the history of logical thinking is very ancient. Historical narratives describe an episode in which Pharaoh observed a sequence of symbolic events interpreted as "seven lean cows devouring seven fat cows" and "seven green ears of grain followed by seven dry ones" [6].

It is widely recognized that these events were interpreted as a forecast of seven years of abundance followed by seven years of famine. This interpretation reflects a high level of analytical thinking, forecasting ability, and understanding of resource cycles.

Thus, the problem of rational accumulation (stockpiling), preservation, and storage during periods of abundance arises, as well as the problem of rational distribution during periods of shortage and deficit.

The ability to accumulate reserves and distribute them among the population based on logical reasoning was assigned to a central administrative authority responsible for managing resources. Historical sources indicate that these measures proved effective, confirming the importance of planning and forecasting in resource management [7].

In this context, such a role can be considered analogous to an early form of logistics management. The successful implementation of these tasks demonstrates that the concepts of logical reasoning and organized resource management—now associated with logistics—can be traced back to ancient periods, including the XVII century BC.

It should also be noted that later, similar functional roles appeared in structured systems such as military organizations, where designated individuals were responsible for supply and distribution of provisions. In both cases, the core function remains the same: accumulation, management, and distribution of resources based on rational decision-making.

This raises the question of whether these developments represent coincidence or a consistent evolution of a single functional concept. It is reasonable to assume that these roles are based on the same underlying principles, indicating continuity in the development of logistics-related functions.

Historically, early references to individuals possessing logical thinking and calculation abilities can be found in various sources, while formal recognition of logistics as a defined function appeared later. At this stage, it can be suggested that the conceptual role of a "logician" or logistics coordinator existed long before it was formally defined.

Analyzing the described approach to managing grain supply—procurement during periods of abundance, storage using available technologies, and controlled distribution during periods of shortage—it can be concluded that the underlying principles were based on efficiency and rational resource utilization.

The organization of container transportation on vessels ensures a high level of efficiency and resource optimization within the transport system. At the same time, it should be noted that the use of dedicated container vessels with capacities below 800 TEU is often inefficient under certain operational conditions.

In the case of the Caspian Sea, the relatively short transport distance and the limited number of containers transported via wagon-platform ferry systems (84 TEU or 42 units of 40-foot containers) reflect the current operational constraints and highlight the need for a more advanced logistics and transport-technological solution. Furthermore, the anticipated increase in railway capacity and cargo flow in this direction requires corresponding improvements in maritime logistics and vessel operations.

The proposed progressive method is aimed at maximizing port cargo turnover, improving the utilization of vessel deadweight and cargo capacity, and enhancing the operational flexibility of ferry transportation. It is well established that transport efficiency is directly related to the degree of utilization of vessel capacity, which plays a critical role in the overall transport process.

The existing wagon-based container transportation on Ro-Pax ferries in the Caspian Sea leads to a significant reduction in effective cargo capacity and commercial payload. In this context, the proposed transition to direct container loading—eliminating non-revenue cargo in the form of wagons—represents a key element of an optimized logistics approach [1,4,5].

In current operations, 40–42 wagon platforms, each with an approximate weight of 22 tons and volume of 67.2 m^3, are used to transport an equivalent number of containers (2TEU). This results in an additional non-productive load of approximately 1000 tons and 2850 m^3, effectively acting as unnecessary ballast.

Consequently, operational costs associated with fuel consumption, labor, and equipment usage, as well as inefficiencies related to wagon circulation, significantly reduce the economic performance of maritime transport operations. At the same time, the expected growth in cargo volumes necessitates improvements in port transshipment processes and infrastructure readiness.

From an operational perspective, transporting the equivalent cargo volume of 3–4 railway trains using a single ferry instead of multiple vessels provides clear efficiency advantages. Although individual container handling may increase loading time, the reduction in the number of voyages and associated operational costs results in overall system optimization.

The proposed replacement of wagon-based transport with direct container loading enables an increase in the number of containers per voyage by approximately 3–4 times, significantly improving transport profitability. Increasing the share of commercial cargo enhances port throughput, reduces logistics costs, and aligns with the interests of shipowners, operators, and cargo stakeholders.

The implementation of this approach does not require major structural modifications to Ro-Pax vessels; however, it may require modernization of port handling infrastructure (Fig. 3). In particular, the replacement of conventional gantry cranes (Fig. 3a) with more efficient container handling equipment (Fig. 3b) is recommended. Such equipment is capable of achieving container handling cycles of approximately 2 minutes or less and supports safe parallel cargo operations.

Fig. 3. Port cargo handling equipment:
a – gantry crane;
b – container handling system.

The analysis indicates that a block train consisting of 55 containers (2TEU), originating from Xi'an (China), was transported from the port of Aktau (Kazakhstan) to the port of Baku using a feeder container vessel ("Sunkar"), with cargo handled on a unit-by-unit basis (Fig. 4).

Fig. 4. Handling of container cargo transported from Xi'an (China) to Baku.

Considering the current logistics scheme, if 42 out of the 55 containers are transported by the Azerbaijani side using Ro-Pax vessels, the remaining 13 containers create a logistical imbalance and handling challenge. This highlights the limitations of the existing transport configuration.

Therefore, the analysis is based on the current loading technology (cargo plan) applied on Ro-Pax ferries capable of transporting containers on 42 wagon platforms (e.g., "Ak. Zarifa Aliyeva" and "Azerbaijan" [8]). The study evaluates two transport scenarios: container transportation using wagon platforms and direct container transportation without wagons.

The objective is to determine the maximum number of containers that can be loaded within the vessel's net cargo capacity and to assess the need for developing an optimized cargo plan.

Under the existing Ro-Pax configuration, a 14-meter wagon platform is arranged in two rows: 12 units (6+6) on the lower deck and 30 units (2×9 + 2×6) on the upper deck, resulting in a total of 42 wagon platforms. When each wagon carries one 40-foot container, the total transported cargo equals 42 units of 2TEU (Fig. 5).

Thus, a Ro-Pax ferry transports a total of 42 containers, with 30 containers on the upper deck and 12 on the lower deck. Assuming an average container mass of $q_k = 30$ tons, the actual commercial cargo mass can be determined, excluding the non-revenue ("zero") weight of wagon platforms.

$$Q_{1fk} = n_{1k} \bullet q_k = 42 \bullet 30 = 1260 \text{ t}, \quad (1)$$

Where: Q_{1fk} - actual mass of commercial cargo under wagon-platform transport conditions, t;

n_{1k} - actual number of 2TEU containers under wagon-platform transport conditions, units;

q_k - the nominal mass of one 2TEU container, t.

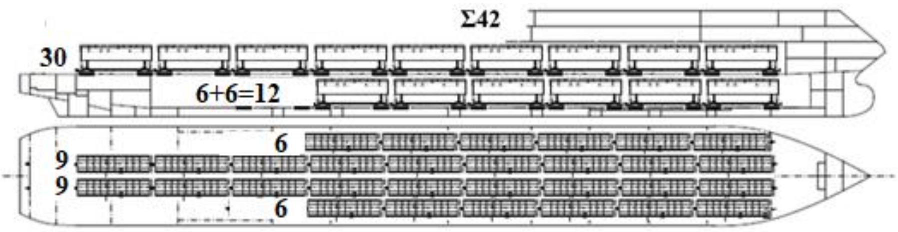

Fig. 5. Current loading arrangement of 42 forty-foot containers on a Ro-Pax vessel for wagon-platform transport conditions.

For the purpose of the analysis, the net cargo capacity (Q) of the Ro-Pax vessel is determined based on its deadweight (D) and ship stores (G).

$$Q = D – G = 5756 - 555 = 5201\text{t}. \quad (2)$$

Based on the net cargo capacity (Q) and the actual commercial cargo loaded (Q_{1fk}) for wagon-platform transport conditions, the cargo capacity utilization coefficient (α_1) of the vessel is determined as follows:

$$\alpha_1 = Q_{1fk} / Q = 1260/5201 = 0.24 \quad (3)$$

Such a low cargo capacity utilization coefficient indicates that the actual operational capability of the vessel is reduced by approximately 4.5 times.

According to the proposed logistics approach, it is intended to eliminate non-revenue ("zero") cargo in the form of wagon platforms (42 units), each with an approximate mass of 22 tons, resulting in a total non-productive load of 924 tons on the investigated Ro-Pax vessels.

A revised loading arrangement is proposed, allowing for the transportation of 160 units of 2TEU containers (equivalent to 320 TEU) of commercial cargo. This configuration includes 137 containers on the upper deck and 23 containers on the lower deck (Fig. 6).

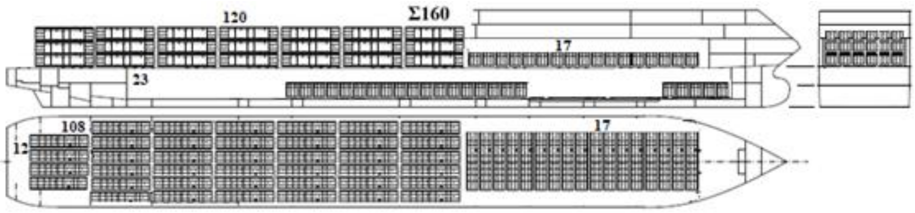

Fig. 6. Proposed loading arrangement of a Ro-Pax vessel with 160 units of 2TEU containers.

It should be noted that the proposed concept is preliminary in nature, and its implementation requires the development of a detailed cargo plan. At the same time, even a simplified configuration—replacing wagon-based transport with single-tier container loading—would allow an increase in container capacity from 42 units to approximately 100–110 units.

However, considering the proposed loading arrangement and the net cargo capacity of the vessel, and assuming the loading of approximately 160–170 units of 40-foot containers (equivalent to 340 TEU), further analysis is carried out to determine the actual transport capacity.

$$Q_{2fk} = n_{2k} \bullet q_k = 160 \bullet 30 = 4800 \text{ t} \quad (4)$$

Or

$$Q_{3fk} = n_{3k} \bullet q_k = 170 \bullet 30 = 5100 \text{ t} \quad (5)$$

Where: Q_{2fk} - *actual mass of commercial cargo for 160 containers, t;*
Q_{3fk} - *allowable mass of commercial cargo for 170 containers, t.*
n_{2k} - actual number of containers, n_{2k} =160 units;

n_{3k} – allowable number of containers, n_{3k} = 170 units;

If it is assumed that the elimination of non-revenue ("zero") cargo in the form of wagon platforms makes an increase in the actual cargo capacity feasible, then the cargo capacity utilization coefficients of the vessel can be determined for transport scenarios involving 160 and 170 units of 2TEU containers per voyage.

$$\alpha_2 = Q_{2fk} / Q_t = 4800/5201 = 0.92 \quad (6)$$

or

$$\alpha_3 = Q_{3fk} / Q_t = 5100/5201 = 0.98 \quad (7)$$

Where: α2 and α3 - cargo capacity utilization coefficients of the vessel corresponding to 160 and 170 containers, respectively.

As is generally accepted, $\alpha>1$ is not permissible, while $\alpha=1$ represents full utilization but is not practically achievable in maritime transport due to operational constraints. Values of $\alpha\geq0,7$ are typically considered acceptable or indicative of efficient vessel utilization.

The obtained high values of the cargo capacity utilization coefficients confirm the effectiveness of the proposed logistics and technological approach within the transport process.

2.1 Analysis of the obtained results.

The graphical representation of the proposed progressive method for container transportation in the Caspian Sea, supported by both theoretical and practical considerations, confirms its significance.

Further analysis focuses on evaluating the impact of replacing non-revenue ("zero") wagon loads with effective commercial cargo, as proposed in this method, on the operational productivity of Ro-Pax vessels.

In this context, the productivity of a transport vessel (W_d) over a given time period is defined as the product of the number of voyages performed (Z_d) and the actual transported cargo volume (Q_f).

$$W_d = Q_f \cdot Z_d \; , \quad (8)$$

$$Q_f = Q \cdot \alpha \; , \quad (9)$$

Where: Q_f – actual amount of cargo transported, t;
Z_d – number of voyages performed by the vessel over the considered period;
α –utilization coefficient of the vessel cargo capacity.

The number of voyages performed by the vessel over the considered period is determined as follows:

$$Z_d = \frac{T_i}{t_{ts}} = \frac{T \cdot k}{t_y \cdot (n-1) + t_{lm} \cdot n} \quad (10)$$

Where: T_i - number of operational days of the vessel within the calendar period;
t_{ts} - time required to complete one transport cycle;
T - total number of available vessel days within the calendar period;
k - coefficient of utilization of vessel operational days in the calendar period;
t_y - average sailing time between two ports;
n - average number of ports served within one transport cycle;
t_{lm} - average time spent by the vessel in port.

By substituting the expressions for actual cargo transported (9) and number of voyages (10) into equation (8), the vessel productivity over the considered period can be expressed as follows:

$$W_d = Q_f \cdot Z_d = \frac{Q \cdot a \cdot T_i}{t_{yol}(n-1) + t_{lm} \cdot n} \quad (11)$$

The conducted analysis demonstrates that the proposed approach increases vessel transport productivity by approximately 75%, while the number of containers transported per voyage increases by 4–5 times.

3 Conclusions

1. The economic efficiency of maritime transport in the Caspian region is directly linked to ensuring continuity in container transportation.
2. Wagon-free transport on Ro-Pax vessels provides additional advantages for the transportation of general cargo, including wheeled equipment.
3. The implementation of wagon-free container transport on ferries (including Ro-Pax vessels) in the Caspian Sea increases vessel productivity by approximately 75% and container capacity by up to four times.
4. The targeted use of railway wagons improves their operational efficiency by utilizing them for their intended land-based transport function rather than involving them in maritime transport operations, where such use is not operationally necessary.

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