

Evaluating the Impact of Land Bridge as a Complementary Corridor to the Suez Canal

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Abstract

The emergence of transcontinental land-bridge corridors is reshaping the geography of global trade and logistics by offering faster, more resilient and increasingly sustainable alternatives to conventional maritime routes. This paper presents a methodological framework for assessing the competitiveness and potential impacts of land-bridge corridors in intercontinental freight transport. The approach combines multimodal transport modelling, generalized-cost estimation and sensitivity analysis to evaluate how variations in travel time, operating cost, value of time and network performance influence the attractiveness of overland routes compared with traditional sea-based connections such as the Suez Canal. The proposed model integrates maritime and rail segments, computes generalized costs for competing corridors and applies a logit-based mode choice formulation to estimate freight diversion and modal shares under different horizon years and policy scenarios. The framework was applied to a real-world case study analyzing three different corridors representing distinct approaches to enhancing Eurasian connectivity: a fully land-based solution (Eurasian Land Bridge), a sea–land corridor (Iraqi Development Road) and a highly integrated multimodal network designed to increase resilience and strategic diversification (India–Middle East–Europe Economic Corridor). Results demonstrate that land-bridge solutions can capture a significant share of high-value and time-sensitive freight while enhancing the resilience and diversification of Eurasian supply chains. The study provides a transferable analytical tool to support strategic planning and investment decisions in emerging intercontinental transport corridors.

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1. Introduction

In the evolving landscape of global logistics, the connectivity between Asia and Europe has become a defining determinant of trade efficiency and resilience. For more than 150 years,

maritime transport through the Suez Canal has served as the backbone of this connection, handling nearly 12% of global trade and about 30% of containerized flows (Ranzan et al., 2024). Since its inauguration in 1869, the canal has reduced the sea distance between Asia and Europe by about 3,000 nautical miles and cut travel times by roughly nine days compared with the Cape of Good Hope route (Deandreis et al., 2015). Its 2015 expansion doubled capacity and lowered waiting times, consolidating Egypt's ambition to position itself as a global logistics hub within Mediterranean trade systems.

Yet the same features that ensured Suez's dominance have also revealed its fragility. Recent fleet-level evidence quantifies the costs that motivate route diversification. The Ever Given blockage in 2021 halted global traffic for six days and disrupted an estimated USD 57 billion in trade (Ranzan et al., 2024). Tran et al. (2025) modelled 69 Maersk vessels affected by the Ever Given blockage and estimated USD 88.79 million in additional costs, of which USD 76.29 million arose from inventory carrying; rerouting and waiting also generated 44,574 additional tonnes of CO₂. These results show that chokepoint disruption costs depend not only on vessel operations but also on cargo value and delay, reinforcing the relevance of generalized-cost comparisons that include time. In addition, the Houthi movement in Yemen continues to pose significant geopolitical risks in the Red Sea through attacks on commercial shipping and regional military tensions. Yemen is now effectively divided into three parts, with one controlled by the Houthis. Solving this crisis is expected to take a long time due to deeply entrenched political divisions, foreign involvement and the governance challenges within Yemen, regardless of the truce imposed on the Israeli-Palestinian conflict. Together with rising transit fees and congestion, these events underscored the

1 vulnerability of relying on a single maritime chokepoint amid projected trade growth of 73 % by
2 2030 and 300 % by 2050 (OECD, 2016).

3 Academic and institutional attention has shifted toward diversifying and complementing
4 maritime transport through overland, hybrid and multimodal corridors. Wang and Meng (2011)
5 present one of the first quantitative analyses of how emerging landbridge systems in China and
6 Mainland Southeast Asia (CMSA) could reshape the competitive landscape of Asian ports. Using
7 a probabilistic route choice model and Monte Carlo simulations, their study quantifies the potential
8 redistribution of port market shares under alternative landbridge operational scenarios. Their
9 findings suggest that the establishment of efficient intermodal landbridge corridors could
10 significantly reduce reliance on the Malacca–Singapore maritime route and diminish the port of
11 Singapore’s market share, while enhancing the role of ports such as Yangon. Complementarily,
12 Kamarudin (2024) investigates the implications of the proposed Thailand Land Bridge for
13 maritime traffic through the Straits of Malacca, emphasizing how a fully operational corridor could
14 divert vessel movements and relieve congestion in one of the world’s busiest shipping lanes.
15 Together, these studies underscore the growing strategic importance of overland intermodal routes
16 in complementing or substituting traditional maritime chokepoints such as the Suez Canal, offering
17 insights into potential shifts in regional trade dynamics and port competitiveness.

18 The search for resilience has fostered a transition from maritime dependency to multimodal
19 diversification. Among alternative routes, the Northern Sea Route (NSR) across the Arctic Ocean
20 and the Trans-Siberian Route (TSR) across Russia and Central Asia offer distance savings but
21 remain constrained by climatic and regulatory limitations (Ranzan et al., 2024). More operationally
22 mature, however, is the Eurasian Land Bridge, a transcontinental rail and intermodal network

connecting over 30 Chinese and 30 European cities through Kazakhstan, Russia, Belarus and Poland. Initially market-driven, responding to the needs of automotive and electronics global value chains, it has since become a central component of the Belt and Road Initiative (BRI) (Pomfret, 2018; 2021). Empirical analyses show that the Land Bridge provides transit times of about less than half of maritime shipping (Schramm and Zhang, 2018). Its success relies on “servicification” rather than infrastructure alone: coordination among logistics operators, customs harmonization and digitalization reduce border delays and transaction costs (Pomfret, 2018). The European Commission’s strategy (2018) explicitly promotes this sustainable, comprehensive and rules-based connectivity, seeking interoperability between Trans-European Transport Network (TEN-T) corridors and Asian systems to enhance the reliability and environmental performance of long-distance freight.

Subsequent quantitative studies have refined the market boundary between rail and sea. Lu et al. (2019) showed that destination location, freight rates and time costs jointly determine the rail-sea competitive frontier: including time costs changed the estimated ratio between land-preferred and sea-preferred areas from about 1:2 to 1:1. Zhang and Schramm (2020) identified a distinct market niche for Eurasian rail freight between maritime and air transport, particularly for time-sensitive goods and intermediate cargo values. From the demand side, Li et al. (2020) found reliability to be the most important China Railway Express service attribute, showing that service quality cannot be represented by monetary cost and transit time alone.

More recently, Mohseni et al. (2025) applied a generalized chain-cost model to seven Eurasian city pairs. Rail costs were on average 1.5 to 2 times maritime costs, but the gap narrowed for inland origins; longer trains reduced generalized rail costs by more than one third, while border capacity,

directional imbalance and connections to the TEN-T network remained decisive conditions for modal shift.

In recent years, the railway network across Middle Eastern countries is under development, with some routes already operational and most others in advanced stages of planning. This emerging rail infrastructure, connecting the Arabian Sea directly to Europe by land or to the Mediterranean Sea, has shown potential as a promising complement to the Suez Canal for specific origins, destinations and product types (Alam et al., 2024). Such connectivity could be particularly attractive for time-sensitive or high-value goods moving between the Asia-Pacific region and Europe. Moreover, these corridors could greatly enhance the resilience of the multimodal transport network between Asia and Europe by offering reliable landbridge alternatives to the Red Sea and Suez Canal passages. In addition, these solutions could also bring efficiencies to shipping organization by reducing load variations along maritime routes and allowing a larger share of the fleet to focus on intra-Asia movements. Concerning the India–Middle East–Europe Economic Corridor (IMEC) Khan et al. (2025) combined gravity modelling with GIS-based network analysis and found that lower economic distance and stronger port-hinterland connectivity can increase trade interaction among corridor members. However, authors do not compare the complete chain of sea legs, rail legs and transfers against Suez.

Within Europe, modal shift remains a policy priority for achieving decarbonization and network efficiency. The EU White Paper on Transport (2011) targeted a transfer of 30 % of road freight over 300 km to rail or inland waterways by 2030 and 50 % by 2050 (Tavasszy and van Meijeren, 2011). Achieving this goal requires both infrastructural and behavioural change.

1 The CE Delft (2018) study on Modal Choice Criteria in Rail Transport identifies cost, reliability
2 and delivery time as the decisive factors for shippers' choices. Rail is competitive when it ensures
3 just-in-time performance comparable to road or air, especially for high-value or conditioned goods.
4 However, structural barriers, interoperability issues, border formalities and limited capacity, still
5 constrain its scalability.

6 Recent cost benchmarking (van der Meulen et al., 2020) indicates that inland waterways remain
7 the most energy-efficient mode, though geographically constrained, confirming that integrated
8 corridors combining rail, road and maritime interfaces can achieve both cost and environmental
9 advantages, provided that digital coordination and terminal efficiency are ensured.

10 The present study aims to investigate the emerging role of land bridge corridors as alternative
11 or complementary transport systems to the Suez Canal for intercontinental trade between Asia, the
12 Mediterranean Sea and Europe. The analysis focuses exclusively on containerized freight, as bulk
13 transport involves substantially different and, in many cases, less credible modal alternatives.
14 While the Suez Canal remains the backbone of Eurasian maritime logistics, the growing
15 complexity of global supply chains, recurrent disruptions and geopolitical reconfigurations
16 highlight the need to diversify transport routes and enhance resilience through multimodal and
17 overland connections.

18 Within this context, the research pursues the objective of assessing the strategic and operational
19 impact of land bridge systems on the broader Asia–Europe logistics architecture. Specifically, this
20 objective is examined through the case study of three different corridors representing distinct
21 approaches to enhancing Eurasian connectivity: a fully land-based solution (Eurasian Land
22 Bridge), a sea–land corridor (Iraqi Development Road) and a highly integrated multimodal

network designed to increase resilience and strategic diversification (IMEC). These corridors differ significantly in their governance models, modal composition and strategic objectives.

The first is the Eurasian Land Bridge, a predominantly rail-based corridor connecting China and East Asia to Europe through Central Asia and Eurasia. As a fully land-based route, it offers shorter transit times than maritime transport and reduces dependence on maritime chokepoints.

The second is the Iraqi Development Road (DR), which, according to Alam et al. (2024), stands out as one of the most promising alternatives due to its potential to provide a direct connection to Turkey and Europe, without the need for transshipment through a Mediterranean port. Moreover, this project appears less complex to implement from a geopolitical perspective compared to other regional initiatives, thanks to the recent stabilization and pacification process underway in Iraq, which constitutes a key transit country along the route. This corridor, linking the Grand Faw Port on the Persian Gulf with Turkey and Europe through a 1,200 km multimodal route, represents a novel instance of Southern Eurasian connectivity.

The third is the India–Middle East–Europe Economic Corridor (IMEC), a more complex multimodal network integrating maritime and rail segments across India, the Gulf countries and Europe. Beyond improving connectivity, IMEC aims to diversify trade routes and reduce reliance on critical maritime chokepoints by distributing flows across multiple transport modes and strategic nodes.

Using these case studies, the research develops and applies a quantitative assessment model to evaluate the comparative performance of the three alternative corridors against the traditional Suez route, with particular reference to transport costs, transit times and overall network efficiency. The model integrates parameters such as transit distance, intermodal transfer times, energy costs and

tariff differentials. A sensitivity analysis is performed to evaluate the robustness of the model's results under varying assumptions; thus, providing a realistic assessment of the corridor's competitiveness under different geopolitical and economic scenarios.

Ultimately, the study aims to contribute to the ongoing academic and policy debate on the future of Eurasian connectivity by providing an empirically grounded and analytically supported evaluation of how overland corridors can function as complementary infrastructures to the Suez Canal, reinforcing the resilience, sustainability and diversification of global trade routes between Asia and Europe.

The remainder of this paper is organized as follows: Section 2 describes the methodology adopted, Section 3 reports the application to the real case study. Finally, Section 4 discusses the main conclusions.

2. Methodology

The methodological framework developed in this study is designed to evaluate the competitiveness of intercontinental freight corridors and can be applied to any existing or planned multimodal route connecting Asia, the Middle East and Europe. The approach allows for the comparison between traditional maritime transport and alternative land-bridge solutions, assessing how variations in travel times, costs and operational parameters influence modal choice and corridor attractiveness.

The model is based on a sequential process consisting of three main steps:

- Estimation of travel times for each transport segment;
- Estimation of transport costs, disaggregated by mode;

- Computation of generalized costs and mode choice analysis.

2.1. Estimation of transport times

Travel times are determined by decomposing the total journey into its maritime and land segments. For maritime transport, distances and average speeds are derived from public databases and shipping line information (sea-distances.org, MSC website). For rail transport, distances and average speeds are based on available data from international freight services (trainonrails, EU).

The methodology can be applied to any corridor, provided that reliable data are available for each segment. The total travel time for route (*i*) is calculated as the sum of the sea and land components plus intermodal transfer times at ports and terminals:

$$T_i = T_{sea} + T_{rail} + T_{transfer} \quad (1)$$

where:

- T_i = total travel time for route (*i*)
- T_{sea} = travel time on sea mode
- T_{rail} = travel time on railway
- $T_{transfer}$ = transfer time

2.2. Estimation of transport costs

Transport costs are assessed from the perspective of logistics service providers, using operating costs rather than market tariffs. This choice assumes that these costs are, to some extent, correlated with the overall service tariff structure in the long-term period even if maritime container tariffs

are subject to greater variability. The total cost per TEU is computed as the sum of all relevant cost categories associated with the modes employed.

For maritime transport, the cost structure follows Ge et al. (2021) and includes:

- Capital costs (ship financing and depreciation). When the vessel is financed by the shipowner or operator, the capital cost includes interest and capital repayments. This cost is generally considered fixed in the short term; however, if the operator is not the shipowner, it may represent a variable cost in the form of a charter rate. In cases where the operator leases the vessel, the lessor (the legal owner, which may be an individual, company, or bank) transfers the vessel to the shipping company, which, in exchange for periodic lease payments, is entitled to use it as its own for an agreed period. The capital cost also encompasses expenses associated with the installation of Emission Control Devices (ECDs) on the vessel;
- Operating costs (crew, insurance, administration, maintenance). This category includes crew wages, insurance premiums, maintenance and repair costs, marine insurance and Protection & Indemnity (P&I) coverage, as well as management expenses;
- Voyage costs (fuel, canal tolls, port charges). This cost component covers fuel costs, port charges, variable costs and emission control costs. Fuel costs are divided into heavy fuel, such as intermediate fuel oil (IFO380 or IFO180) and light fuel, such as marine diesel oil or marine gas oil (MGO). A distinction must be made between fuel costs incurred at sea (which depend on sailing distance, speed, daily fuel consumption and heavy fuel price) and those incurred in port (which depend on daily fuel consumption in port and light fuel price). Port costs comprise the port disbursement account (PDA) and the Suez Canal transit fee. Variable costs refer to the

transport costs associated with carrying loaded and empty containers. Emission control costs cover the operation, maintenance and repair of ECDs.

Accordingly, the voyage cost is expressed as follows:

$$C_{Voyage} = C_{Fuel} + C_{Port} + C_{Var} + C_{Emission} \quad (2)$$

where each term is computed using the analytical expressions derived from Ge et al. (2021).

For rail transport, the adopted methodology is based on van der Meulen (2020) and includes:

- Fixed costs, subdivided into three sub-categories: Lease of locomotives; Lease of wagons; Lease of auxiliary assets.
- Variable costs, represented by energy consumption;
- Staff costs, comprising wages and related social charges for train drivers;
- Mode-specific costs, including track access and shunting;
- General operating costs. This category comprises expenses related to administration, communication, overhead and associated items. Within this cost component, the expenses incurred for parking trains on stabling tracks are also included. Generally, general operating costs are expressed as a percentage of the total cost.

Thus, the total travel cost for railway has been calculated as follows:

$$C_{railway} = 1.15 \times [D_r \times (C_{var} + C_{mod-spec}) + TT_r \times (C_{fix} + C_{staff})] \quad (3)$$

Where:

- $C_{railway}$: Total cost for railway;
- C_{var} : Variable costs;

- 1 • $C_{\text{mod-spec}}$: Mode-Specific costs;
- 2 • C_{fix} : Fixed costs;
- 3 • C_{staff} : Staff costs;
- 4 • D_r : Travelled distance by railway;
- 5 • TT_r : Travel time of railway.

6 The cost amplification factor has been set to 1.15 to account for the effect of the increased train
 7 length compared to the reference model. All costs are normalized per TEU to ensure comparability
 8 between modes. This methodology allows the evaluation of cost structures for any corridor
 9 configuration, considering energy prices, infrastructure charges and other region-specific factors.

10 *2.3. Computation of Generalized Costs and Mode Choice*

11 The generalized cost (GC) expresses the combined effect of monetary and temporal components
 12 on freight routing decisions. For each route (i), the GC (Tavasszy and van Meijeren, 2011), is
 13 defined as:

$$14 \quad GC_i = C_i + VOT * T_i \quad (4)$$

15 where:

- 16 • GC_i = generalized cost for route (i)
- 17 • C_i = total operating cost [€/TEU]
- 18 • VOT = value of time [€/h per TEU]

19 The value of time is related to the opportunity cost of capital immobilized during transport and
 20 depends on the nature and value of goods. The choice of mode, for international freight, has to be

determined by the service quality offered by all modes and the preferences of shippers and logistic service providers according to Tavasszy and Van Meijeren, 2011. The model of mode choice applied most often is based on the trade-off between the out-of-pocket costs of transport (the tariff paid by the shipper) and the transit time between origin and destination. Transport time is weighted by the value of time. The weighted sum of tariffs and time is called Generalized Cost of transport and determines the attractiveness of transport modes. Shippers will choose those alternatives that have the lowest generalized costs.

The VOT of transport is closely related to the logistics characteristics of goods. Time-related cost drivers include physical characteristics, such as the value density goods, their perishability, as well as other characteristics, such as order lead-time and production technology.

After the computation of the generalized cost for each route under investigations, it is possible to assess the route choice by using the multinomial logit model. A nested logit structure has been considered but not adopted since all the alternatives are assumed to belong to the same decision level and no hierarchical grouping among them can be justified. In fact, the routes represent markedly different transport solutions, characterized by distinct combinations of maritime and rail segments and by substantially different operational characteristics. Therefore, the standard logit formulation has been deemed appropriate for capturing the competition among these mutually exclusive alternatives.

3. Case Study

The case study is based on a comparative analysis of the three distinct models of intercontinental connectivity, previously described, that may serve as alternatives or complements to the traditional

Suez Canal route for freight transport between Asia and Europe. The Suez Canal remains the dominant maritime gateway connecting the two continents but recent geopolitical tensions, supply chain disruptions and concerns over the vulnerability of strategic maritime chokepoints have renewed interest in alternative Eurasian transport corridors. The Eurasian Land Bridge is a predominantly rail-based corridor crossing the Eurasian continent; the DR combines maritime transport in the Gulf with overland rail and road infrastructure through Iraq and Turkey while the IMEC integrates maritime and rail networks across South Asia, the Middle East and Europe.

Table 1 summarizes the main characteristics of the four corridors considered in the analysis. For each corridor, the table highlights the prevailing governance model, its principal competitive advantage and the main operational or strategic limitations affecting its development and performance.

Table 1. Corridor comparison.

Corridor	Governance Logic	Main Advantage	Principal Limitation
Suez Canal	Centralised maritime infrastructure with tariff control	Economies of scale, established global route	Congestion, geopolitical risk
Eurasian Land Bridge	Transnational coordination via logistics alliances	Speed, reliability, environmental benefit	Capacity and interoperability constraints
India-Middle East-Europe Economic Corridor	Multilateral corridor governance based on intergovernmental cooperation and coordinated infrastructure investment	Diversification of trade routes, strengthened supply-chain resilience and regional economic integration	Complex cross-border coordination, geopolitical uncertainty and implementation risks

Iraqi Development Road	State-led multimodal integration	Shorter transit, regional diversification	Capacity constraints, security, financing and governance complexity
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Integrating the Suez–Mediterranean–Gulf axis with overland networks like the Iraqi Development Road, the IMEC and the Eurasian Land Bridge could generate a multimodal triangle linking the Persian Gulf, the Mediterranean and Northern Europe, enhancing supply-chain resilience and fostering regional economic cooperation.

Seven specific origin–destination pairs have been selected as representative relations between China and Europe or the Middle East to quantify this competitiveness:

- Shanghai (China) – Duisburg (Germany);
- Shanghai (China) – Vienna (Austria), Zagreb (Croatia), Ljubljana (Slovenia), Belgrade (Serbia), Budapest (Hungary), Bratislava (Slovakia), Munich (Germany);
- Shanghai (China) – Milan (Italy), Zurich (Switzerland);
- Shanghai (China) – Paris (France);
- Shanghai (China) – Madrid (Spain);
- Shanghai (China) – Istanbul (Turkey), Sofia (Bulgaria), Bucharest (Romania);
- Shanghai (China) – Warsaw (Poland), Copenhagen (Denmark), Prague (Czech Republic), Berlin (Germany).

For each of these routes, generalized transport costs and times are computed under four scenarios, following the four corridors (Figure 1):

1 a) via the Suez Canal, using maritime mode till respectively, depending on destination, the
2 ports of Rotterdam

3 (Netherlands), Trieste (Northern Italy), Genova (Northern Italy), Le Havre (France), Valencia
4 (Spain), Istanbul (Turkey) or Hamburg (Germany) and subsequently proceeds by land transport to
5 the final destinations.

6 b) via Iraqi Development Road, the corridor combines a maritime leg from Shanghai to the new
7 port of Al-Faw with inland rail transport along the DR corridor up to the Turkish border. From
8 there, freight continues through the European rail network until reaching the respective
9 destinations.

10 c) via IMEC, this corridor is characterized by an initial sea leg connecting Shanghai with Jebel
11 Ali Port, followed by rail transport across Saudi Arabia, Jordan and Israel. Upon arrival at the Port
12 of Haifa, cargo is transferred back to maritime transport and subsequently reaches the final
13 destinations through the same routing pattern adopted for the Suez corridor.

14 d) via Eurasian Land-Bridge (China-Europe), the land-based alternative relies entirely on rail
15 transport from China, passing through Kazakhstan and Russia before entering the European
16 railway system, which provides the final distribution to the destinations considered.

17

18 The year 2040 has been selected as the reference horizon for the analysis, as it is expected that
19 by then the land railway corridor toward Europe will be fully operational while the Suez Canal
20 may begin to experience capacity constraints. The current configuration of the Suez Canal will
21 have the capacity to satisfy demand for another decade more or less also with the
22 implementation of an updated vessel management and congestion-based toll system.

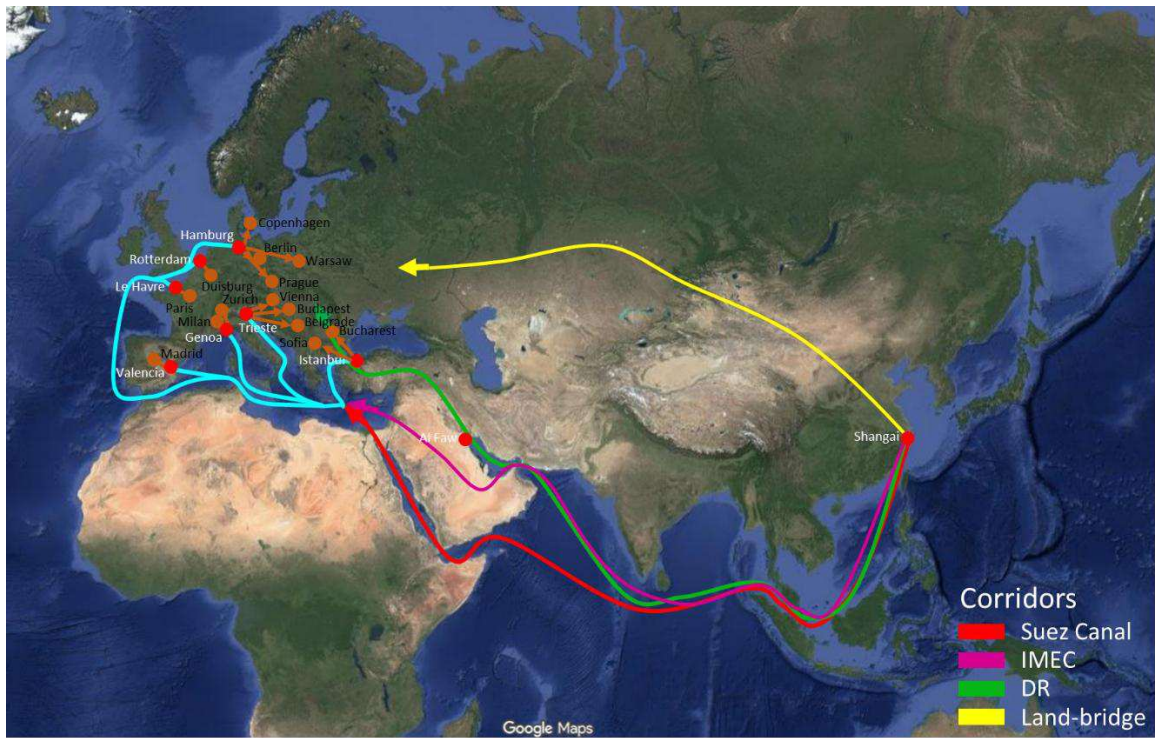


Figure 1. Alternative corridors analyzed.

3.1. Assessment of travel times

The first step in defining the input data for the mode choice model applied to the corridors analyzed concerns the estimation of travel times. Travel times are calculated by decomposing each connection into its constituent segments: maritime (by ship) and land-based (by rail).

Sea travel distances and times were computed using specialized maritime distance platforms (e.g., sea-distances.org, msc.com), while for Al-Faw, reference data were derived from comparable ports such as Umm Qasr and Jebel Ali. Rail travel times were determined using publicly available sources on intercity rail distances (trainonrails and European Commission's travel cost), complemented by technical data from BALO Transport & Logistics.

An average operational speed of 45 km/h was adopted for freight trains in the Middle East, consistent with recent performance improvements observed along Eurasian corridors and with the expected operating conditions of the new Iraqi and Saudi Arabia railway infrastructure. In Europe and Türkiye, railway speeds are reduced to 25 km/h for reflecting operating and topological conditions with congestion in major rail freight corridors and capacity constraints at the main network nodes in major metropolitan areas. In many of these areas, passenger trains receive priority track and terminal access over freight trains. Both assumptions reflect the readiness of connecting networks (including border interoperability, Bosphorus crossing and the Turkey–Iraq link) and are further supported by observing recent reductions in Silk Road rail transit times, which now achieve regular services of approximately 10 days between Xi’an and Duisburg.

Thus, travel times for each route were obtained by summing maritime and rail segments, considering distances, speeds and average intermodal transfer times at major hubs.

3.2. Assessment of travel costs

The second step involves estimating travel costs for each segment of the routes under comparison. The analysis considers separately the maritime and railway components, adopting methodologies established in recent transport economics literature. In all cases, costs represent operating expenses incurred by logistics service providers, rather than tariffs charged to shippers.

For maritime transport, the calculation follows Ge et al., 2021, which disaggregates the total trip cost into three components, as reported in the methodology section. For railway transport, input data (in EUR) were obtained from van der Meulen, 2020 base parameters for container shuttle trains with a capacity of 105 TEU ($\approx 1,150$ t gross), updated to current price levels, particularly

for energy costs. The resulting cost functions were applied to compute total transport costs by mode and by route. To ensure comparability, the total cost was divided by the effective carrying capacity of each transport vector, yielding a cost per TEU.

This process yields comparable unit transport costs for both maritime and rail alternatives, allowing direct comparison between the Suez Canal and other multimodal routes.

3.3. Mode choice model for international freight

The final step concerns the mode choice model applied to estimate the potential shift of freight flows from the traditional Suez Canal route to the three corridors identified. The model assumes that shippers and logistics service providers select the option with the lowest generalized cost, reflecting the trade-off between monetary costs and transit times.

The VOT reflects the opportunity cost of capital immobilized in transit and depends on cargo characteristics such as value density, perishability and order lead time. For this application, the value of 0.5 US/ton-hour from Alam et al. (2021) is utilized corresponding to a VOT consistent with the average value manufactured freight typically moved on Asia–Europe routes with an annual depreciation rate of about 10%. Since freight tariffs are volatile and difficult to forecast, operating costs are used instead of market tariffs. This approximation is acceptable especially for relative comparisons, as mark-ups tend to vary within a narrow range.

Once the generalized costs for both the Suez and the new multimodal routes are computed, the multinomial logit model is applied to estimate the probability of choosing the new corridors. Applying the model to the seven specific origin–destination pairs selected as representative relations between China and Europe or the Middle East, allows to quantify the competitiveness

and the expected share of freight diverted from maritime to the new multimodal transport routes identified.

Traffic volumes used for calibration derive from MDS Transmodal (MDST) datasets, which quantify total annual loaded TEU flows from China and Japan to Europe and the Middle East.

Assuming as reference the values of attributes of the Suez route, where, for instance, the average travel time by sea is about 30 days, Tab.2 reports, for the alternative routes, the ratios of each attribute and of the resulting generalized cost with respect to the corresponding values assumed for the Suez corridor. Specifically, the mean, minimum and maximum values of the generalized cost are shown to highlight the variability associated with the different destinations considered.

The comparative analysis of travel times and costs (not reproduced here in numeric form) confirms that maritime transport via the Suez Canal remains the least expensive option in pure cost terms per TEU but the slowest in delivery time. Typical door-to-door maritime times from Shanghai to European destinations (Rotterdam, Trieste, Hamburg, etc.) exceed 30–35 days, while routes integrating the Al-Faw Port and the Development Road rail corridor could potentially reduce overall transit time by 10–15 days, depending on the destination.

Conversely, the unit cost of transport for the rail-based corridor remains higher due to energy costs, track-access charges and reduced economies of scale. Nevertheless, when translated into generalised costs (combining time and operating cost weighted by the value of time, VOT), the other alternative corridors achieve competitive equivalence for time-sensitive goods or in high fuel-price scenarios.

Table 2 Attribute for maritime and rail transport and generalized cost ratios relative to the Suez corridor

Corridor	Transit	Transit	Travel	Travel	Generalized Cost		
	times by sea	times by rail	cost by sea	cost by land	Mean	Min	Max
Shangai – Europe (via DR)	0.57	8.13	0.72	9.60	1.12	0.97	1.21
Shangai – Europe (via Land- Bridge)	0.79	25.18	0.06	26.16	1.46	1.41	1.53
Shangai – Europe (via IMEC)	0.76	4.49	0.82	5.84	1.16	1.12	1.17

1

2 The results highlight substantial differences in the composition of transport time and cost across

3 the three corridors. The DR corridor combines moderate maritime transport requirements with a

4 significant rail component, resulting in an average generalized cost of 1.12, the lowest among the

5 alternatives considered. The Land-Bridge corridor, relying exclusively on overland transport,

6 exhibits the highest rail transit time (25.18) and land transport cost (26.16), which translate into

7 the highest average generalized cost (1.46). In contrast, the IMEC achieves a more balanced

8 distribution between maritime and rail segments, with the shortest rail transit time (4.49) and an

9 average generalized cost (1.16) only marginally higher than that of the DR route. These findings

10 suggest that corridor competitiveness is not determined solely by the reduction of maritime

11 transport distances but rather by the overall trade-off between maritime and inland transport

12 components. In particular, the efficiency gains associated with DR stem from its ability to limit

13 the time and cost burden of the land segment while maintaining a relatively efficient maritime

14 connection.

1 The results of the mode choice model for the alternative corridors are presented in Table 3. The
2 application of the model indicates that the IMEC corridor does not emerge as a sufficiently
3 attractive option to capture a significant share of traffic when compared with the other available
4 routes. Similarly, the Land-Bridge corridor shows only limited competitiveness, with a marginal
5 potential market share restricted to a small number of destinations in Eastern Europe, where its
6 geographical configuration may provide some advantages. Consequently, the analysis focuses on
7 the two routes that exhibit the greatest potential for attracting freight flows, namely the
8 Development Road (DR) corridor and the traditional Suez Canal route. Table 3 therefore reports
9 the mode choice results and the corresponding market shares derived from the comparison between
10 these two competing alternatives.

11 The modal split results reveal a highly heterogeneous pattern across the destinations considered,
12 highlighting the varying competitiveness of the DR corridor relative to the traditional Suez Canal
13 route. The DR corridor emerges as the dominant option for Bulgaria, Romania and Turkey where
14 it captures almost the entire market share (99%). This outcome reflects the geographical advantage
15 of the corridor for destinations located in Southeastern Europe and the Eastern Mediterranean,
16 where the reduction in transit distance and time translates into a substantial decrease in generalized
17 transport costs.

18 By contrast, the Suez Canal route remains overwhelmingly preferred for all other European
19 countries in Central and Western Europe including Poland and the Czech Republic, accounting for
20 99% and 97% of the modal split, respectively. For these destinations, the additional inland
21 transport required by the DR corridor offsets its potential advantages, preserving the
22 competitiveness of the conventional maritime route. Serbia represents an intermediate case, with

a modal split of 67% for the Suez Canal route and 33% for the DR. This result suggests that the two alternatives are relatively close in terms of generalized cost, allowing the DR corridor to capture a significant, although not dominant, share of freight flows.

Overall, the findings indicate that the attractiveness of the DR corridor is strongly destination-dependent. Its competitive advantage is concentrated in Southeastern Europe and neighboring regions, whereas the traditional Suez Canal route continues to be the preferred option for destinations located further north and west within the European market.

Table 3. Results for the mode choice model for the alternative routes.

Routes	Modal split
	(Suez Canal / Development Road)
Shangai – Bulgaria	1% / 99%
Shangai – Czech Republic	97% / 3%
Shangai – Poland	99% / 1%
Shangai – Romania	1% / 99%
Shangai – Serbia	67% / 33%
Shangai – Turkey	1% / 99%

3.4. Sensitivity analysis

The sensitivity analysis was carried out to explore how variations in key input parameters influence the model outputs, thereby increasing understanding of the system's internal dynamics

and verifying the soundness of its assumptions. The results of the analysis, considering data previously shown, is reported only for the DR corridor and the Suez route comparison.

In line with established transport-modelling practice, the analysis serves three main objectives:

- to enhance understanding of how model parameters, affect predicted outcomes;
- to verify the validity of underlying assumptions adopted in the base-case scenario;
- to quantify predictive uncertainty by observing the response of demand forecasts to plausible parameter changes.

The procedure begins with the identification of the most influential and uncertain input variables. For each variable, three values are assigned: 1) a reference value, representing the most probable condition used in the base-case model; 2) a favourable value, representing improved or optimistic conditions; 3) an adverse value, representing deteriorated or pessimistic conditions.

A $\pm 10\%$ variation range relative to the reference value was adopted for all parameters. This range reflects a reasonable balance between empirical variability and model sensitivity while ensuring comparability across scenarios.

Three complementary aspects are investigated. The first is the impact on total transport demand of varying one parameter at a time. The second is the maximum and minimum demand levels obtained within the tested range of each variable while the last is the direction and magnitude of parameter change required to alter the relative attractiveness of competing transport alternatives (i.e., change the “sign” of the forecasted preference). For the freight demand, three key operational variables drive the model outcome: a) sea travel time; b) average rail-freight speed; c) VOT applied

to freight. Each of these parameters was tested across the future time horizon and combined with container-port traffic growth assumptions, producing a total of 8 sensitivity scenarios.

Among these variables, the VOT warrants particular attention. It should not be treated as a universally transferable constant. The meta-analysis by Binsuwadan et al. (2022), covering 106 estimates from 56 studies, found significant variation according to GDP per capita, transport mode and respondent type. This heterogeneity supports testing alternative VOT assumptions and segmenting the results by commodity characteristics when evaluating intercontinental freight corridors as clearly shown by Meersman et al. (2021).

3.4.1. Value of Time (VOT)

Results show that a 10 % increase in VOT raises generalized costs by approximately 4 % for the Suez route and 3 % for the DR route; conversely, a 10 % decrease in VOT lowers generalized costs by about 5 % and 3 %, respectively.

Table 4 summarizes how these changes affect freight demand under different assumptions of container-port traffic growth. As expected, a simultaneous decrease in both port throughput and VOT leads to a notable decline in demand for the DR route (up to –24 %). Conversely, higher VOT values, representing more time-sensitive goods, generate substantial increases in demand (up to +31 %).

This confirms that time sensitivity is a major driver of corridor attractiveness. As logistics chains evolve toward just-in-time operations and higher-value commodities, even moderate increases in VOT strengthen the competitiveness of the faster land-bridge alternative.

Table 4. Freight demand component variation.

Freight demand variation [%]	Container port traffic projections: -10%	Container port traffic projections: 0%	Container port traffic projections: +10%
VOT: -10%	-24%	-16%	-7%
VOT: 0%	-10%	0%	11%
VOT: +10%	7%	19%	31%

3.4.2. Sea-Travel Time

The variation of sea-travel time exhibits the strongest effect among the tested parameters. A 10 % increase in maritime travel time results in a 5 % rise in generalized costs via Suez and roughly 3 % via Al-Faw port and Iraqi DR, while a 10 % reduction produces symmetrical decreases.

Table 5 demonstrates that longer shipping times substantially favor diversion toward the DR corridor: an increase in sea-travel time combined with a +10 % growth in container-port traffic yields demand surges of +41 %. Conversely, shorter maritime times penalize the new route, since the advantage of faster overland transport diminishes.

These results reflect the structural sensitivity of maritime transport to congestion and geopolitical disruption. Any increase in sailing times, due to bottlenecks, slow-steaming strategies, or incidents such as the 2021 Ever Given blockage, would strongly reinforce the relative attractiveness of the DR.

Table 5. Freight demand component variation.

Freight demand variation [%]	Container port traffic projections: -10%	Container port traffic projections: 0%	Container port traffic projections: +10%
Sea travel time: -10%	-30%	-22%	-14%

Sea travel time: 0%	-10%	0%	11%
Sea travel time: +10%	16%	29%	41%

3.4.3. Rail-Freight Speed

As anticipated, changes in railway speed affect only the DR corridor, leaving Suez costs unchanged. A 10 % increase in rail speed reduces generalized costs by about 2 %, while a 10 % decrease raises them by the same proportion.

Table 6 shows that higher rail speeds produce proportional gains in demand (up to +32 %), whereas slower trains lead to marked decreases (−26 %). Although the sensitivity magnitude is smaller than for sea-travel time, it remains meaningful because technological progress, electrification, double-tracking and digital signaling is expected to systematically increase rail performance over the coming decades.

Therefore, the most probable scenario corresponds to the favorable end of the range, reinforcing the robustness of the corridor's long-term competitiveness.

Table 6. Freight demand component variation.

Freight demand variation [%]	Container port traffic projections: -10%	Container port traffic projections: 0%	Container port traffic projections: +10%
Railway speed: -10%	-26%	-17%	-9%
Railway speed: 0%	-10%	0%	11%
Railway speed: +10%	8%	20%	32%

Across all scenarios, the model behaves consistently and as theoretically expected with the transport demand increases with higher VOT, higher rail speed and longer maritime times while the demand decreases when these parameters move in the opposite direction. No anomalous or counter-intuitive responses were observed, which supports the internal validity of the modelling framework. Tables 3, 4 and 5 reveal a clear hierarchy of influence among the variables. Sea-travel time exerts the largest impact on demand, highlighting the corridor's potential role as a resilience mechanism against maritime delays. The VOT follows, confirming the relevance of logistics-service quality in shipper decision-making while the railway speed shows a moderate but positive effect, expected to strengthen as infrastructure upgrades are implemented.

Overall, a $\pm 10\%$ parameter variation produces demand changes ranging from $\pm 5\%$ to $\pm 40\%$, depending on the variable, which is consistent with empirical sensitivity levels in comparable intercontinental freight models.

3.4.4. Global Assessment and Graphical Representation

The global evaluation of sensitivity results demonstrates that model outcomes remain robust under plausible parameter fluctuations. The direction and magnitude of the variations confirm the credibility of the decision-making framework applied at this real case-study.

To visualize these findings, Tornado diagrams were generated for each model component. Figure 2 presents the Tornado diagram for the freight demand. The diagram ranks variables by descending sensitivity, revealing that:

- the projection of container-port traffic exerts a nearly linear effect;
- sea-travel time has the largest amplitude of variation, reflecting its dominant influence;

- VOT shows a slightly non-linear but dampening effect over time, suggesting increasing model resilience;
- railway speed displays moderate sensitivity but a positive technological trajectory, as planned infrastructure upgrades across Iraq, Turkey and the Trans-European corridors are likely to enhance speed rather than reduce it.

Moreover, sea-travel time can be considered relatively stable under normal market conditions, with large deviations expected only in the event of significant geopolitical or climatic disruptions. The most probable long-term trend for both VOT and railway speed is upward, implying increased competitiveness for the DR route relative to the Suez Canal.

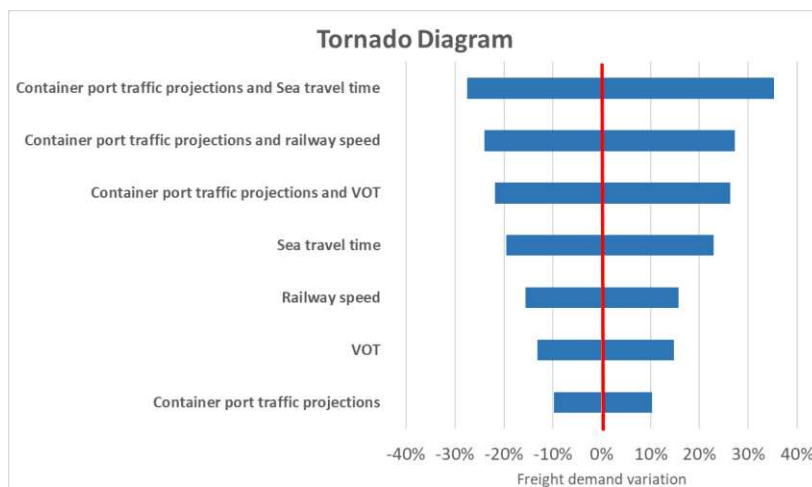


Figure 2. Tornado diagram for the freight demand

4. Conclusion

The comparative assessment of the three alternative Eurasian corridors, the Eurasian Land Bridge, the India–Middle East–Europe Economic Corridor (IMEC) and the Iraqi Development

Road, against the conventional Suez Canal route highlights the continued centrality of maritime transport in Asia–Europe trade while confirming the strategic value of route diversification.

The results indicate that none of the examined corridors is likely to replace the Suez Canal under normal market conditions. The economies of scale offered by maritime transport, combined with the operational flexibility of global shipping networks, continue to provide a substantial competitive advantage. The role of the alternative corridors remains constrained by significantly higher transport and infrastructure costs, substantial investment requirements and long implementation timelines and operational, geopolitical and regulatory challenges that limit large-scale deployment. Nevertheless, the analysis confirms that alternative corridors can play an increasingly important complementary role by enhancing network resilience, reducing dependence on critical chokepoints and offering viable solutions for specific market segments.

Among the three alternatives, the Iraqi Development Road emerges as the most promising corridor in terms of traffic attraction potential. Its hybrid sea–land configuration enables a meaningful reduction in transit times while limiting the number of transshipment operations required. Under favorable conditions, the corridor could attract a significant share of high-value and time-sensitive freight flows, particularly toward Central Europe and destinations in the Eastern Mediterranean region. Rather than competing directly with Suez, the DR appears capable of capturing a strategic share of Asia–Europe traffic, thereby increasing overall network redundancy and resilience.

The Eurasian Land Bridge also demonstrates the ability to serve selected market segments where transit time and reliability are more important than transport cost. However, its attractiveness

remains constrained by capacity limitations, interoperability issues and the operational complexity associated with multiple border crossings and railway systems.

By contrast, the IMEC shows a more limited capacity to attract traffic under standard operating conditions. While strategically relevant from a geopolitical and diversification perspective, the corridor's structure, based on two major maritime segments connected by rail links, requires additional transshipment activities, terminal handling operations and modal transfers. These factors increase both costs and operational complexity, reducing its competitiveness relative to direct maritime services through Suez.

The sensitivity analysis further confirms that the attractiveness of land-based and multimodal corridors increases under scenarios characterized by maritime congestion, rising fuel costs, supply-chain disruptions, or increasing values of time. In such contexts, the DR in particular demonstrates substantial growth potential, reinforcing its role as a resilient complement to maritime transport rather than as a substitute.

An important consideration concerns the assumptions underlying the analysis. The modelling framework implicitly assumes that many of the current operational, institutional and governance barriers affecting international rail and multimodal corridors can be progressively overcome. Although such challenges are significant, international experience demonstrates that successful examples of cross-border railway cooperation, customs integration and corridor management already exist and can provide valuable reference models for future development.

The principal long-term constraint, however, is not governance but physical railway capacity. Unlike maritime transport, which can absorb substantial traffic growth through larger vessels, flexible routing options and a wide range of port gateways, railway corridors are inherently

constrained by infrastructure characteristics. Even highly efficient double-track railways cannot match the throughput capacity of major maritime routes. Capacity limitations emerge both along line segments and, more critically, at strategic nodes such as border crossings, marshalling yards, intermodal terminals and major railway stations. While maritime networks can redistribute traffic among alternative ports, railway systems depend on a relatively fixed set of nodes whose expansion is often costly and time-consuming.

Consequently, the future success of the Development Road, the Eurasian Land Bridge and other comparable corridors will depend not only on infrastructure construction but also on the ability to ensure high levels of operational efficiency, traffic management and node capacity. Their greatest contribution is therefore likely to be the diversification of Eurasian transport networks, providing resilience, flexibility and decarbonization opportunities within a broader multimodal system in which the Suez Canal remains the dominant backbone of Asia–Europe trade.

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