INTERNATIONAL JOURNAL OF
COASTAL, OFFSHORE & ENVIRONMENTAL ENGINEERING

IJCOE Vol.10/ NO.2/Transportation,
transit and maritime transport2025 (32--49)

Available online at: www. Ijcoe.org

Optimizing Marine–Land Trade Corridors through Iraq: A Strategic Evaluation of Eurasian Connectivity via Umm Qasr and Overland Routes

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ARTICLE INFO

Article History:
Received: 29 May 2024
Accepted : 12 Feb 2025

Keywords:
Multimodal transport, Iraq corridor, Eurasian trade, Umm Qasr port, Logistics optimization

ABSTRACT

This study presents a comprehensive evaluation of a proposed transcontinental freight corridor linking East and South Asia to Europe through Iraq, with the aim of enhancing regional connectivity and diversifying global trade routes. Two strategic configurations are modeled: a sea–land corridor via Iraq's Umm Qasr Port (S1) and a fully land-based corridor traversing Iran and Iraq (S2). Using an integrated optimization framework that combines Mixed Integer Linear Programming (MILP) with Genetic Algorithms (GA), the study analyzes each corridor's performance across key logistics dimensions—cost, transit time, and geopolitical risk. Simulation results show that the sea–land corridor (S1) achieves a 12% reduction in cost and a 15% improvement in delivery time compared to traditional maritime routes such as the Suez Canal, while maintaining a moderate risk index. The land-only configuration (S2), though slightly more expensive and slower, offers increased operational sovereignty and resilience against maritime disruptions. Both scenarios are found to be scalable, adaptive to geopolitical conditions, and capable of absorbing up to 20 million tons of freight annually with appropriate infrastructure upgrades. The findings position Iraq as a pivotal node in Eurasian trade, capable of anchoring multimodal logistics systems that combine flexibility, redundancy, and efficiency. Policy implications include the need for investment in port modernization, intermodal infrastructure, and cross-border harmonization, particularly with Iran and Syria. This research contributes to the emerging discourse on resilient trade architecture and offers a replicable decision-support model for infrastructure planners and policymakers seeking to design future-proof transit corridors in geopolitically fragile regions.

1.Introduction

International trade has increasingly become reliant on maritime and multimodal transportation infrastructures, driven by growing intercontinental trade flows between Asia and Europe. Efficient transportation corridors combining maritime ports and overland routes significantly enhance logistics performance by reducing transit time, operational costs, and logistical risks[1,2]. In this context, Middle Eastern countries, notably Iraq, are strategically positioned due to their geographical location bridging the major economic zones of East Asia and Europe. Iraq, in particular, has the potential to emerge as a pivotal logistics hub, thanks to its maritime access via Umm Qasr Port and its land connections facilitating multimodal transport [3]. However, existing infrastructural deficiencies, including inadequate port facilities, outdated logistics equipment, and limited multimodal connectivity, currently hinder Iraq's full potential as a major transit country [4]. Therefore, developing a strategically optimized transit corridor from East Asia (China, India, Pakistan) through Iraq's maritime gateway at Umm Qasr, extending overland to Syrian ports (Latakia, Tartus, or Hamidiyah), and finally reaching Europe (via Greece) could significantly reduce costs and transit times, strengthening Iraq's role in international logistics [5,6]. This study aims to evaluate and optimize this proposed maritime-land transit corridor, comprehensively assessing port capacities, infrastructural readiness, economic viability, and logistical performance.

Strategically situated at the northern edge of the Persian Gulf, the port of Umm Qasr serves as Iraq’s primary maritime gateway, playing a crucial role in the nation’s economic and logistical network [7,8]. Despite this strategic advantage, the port faces significant operational limitations, including insufficient cargo-handling facilities, outdated infrastructure, and inadequate connectivity to the hinterland transportation networks [2,9]. Addressing these infrastructural gaps and enhancing port efficiency through modernization and capacity expansion could transform Umm Qasr into a competitive transit hub for intercontinental freight flows [10]. Furthermore, establishing robust multimodal connectivity linking Umm Qasr to Syria’s Mediterranean ports (Latakia, Tartus, and Hamidiyah) would enhance the maritime-land transit potential, thereby optimizing cargo movement from East Asia toward European markets [11].

Given the geopolitical shifts and the need for diversified global trade routes, developing alternative corridors becomes increasingly imperative for securing resilient logistics networks [12]. Integrating Iraq into global maritime logistics through comprehensive infrastructure development can effectively enhance economic diversification, create employment opportunities, and stimulate regional economic integration [13,14]. Recent research highlights that investments in port infrastructure and hinterland connectivity significantly correlate with increased port throughput and reduced transportation costs, thus enhancing overall logistical performance[15]. Consequently, a thorough assessment of existing infrastructures, coupled with an optimized transit model integrating maritime and land transportation networks, is necessary to leverage Iraq’s geographic advantages fully.

This study proposes and analyzes two plausible transit configurations centered on Iraq: one that utilizes a sea–land–sea route entering Iraq through the Umm Qasr Port and continuing overland through Syria to Mediterranean exit points; and another that follows a fully land-based trajectory across Iran and Iraq. The research framework integrates mathematical modeling, cost-time-risk optimization, and infrastructure assessment to evaluate the strategic viability of each option.

To achieve this, a hybrid optimization model is developed combining Mixed Integer Linear Programming (MILP) and Genetic Algorithms (GA), both of which allow for multi-objective decision-making under real-world constraints. The model incorporates operational data such as transport costs, estimated transit times, infrastructure capacity, and geopolitical risk metrics, enabling a holistic evaluation of corridor performance under diverse scenarios [8,9].

In addition to quantitative modeling, the research considers institutional, policy, and investment factors that influence corridor feasibility. By focusing on Iraq's geographic centrality and its potential to anchor regional trade, this study contributes to ongoing debates on resilient supply chains and the reconfiguration of Eurasian connectivity. The findings are intended to support infrastructure planning, policy formulation, and investment strategies that promote Iraq's role as a dynamic and adaptable logistics hub in an increasingly uncertain global trade environment [16,17].

2.literature Review

The design and optimization of transcontinental freight corridors have attracted growing academic attention in recent years, driven by the surge in global trade flows, rising geopolitical uncertainty, and increased demand for resilient supply chains. Several streams of literature contribute to the theoretical and practical foundation of this study, including port infrastructure development, multimodal logistics optimization, and regional corridor planning in geopolitically complex regions[18,19].

Modern port infrastructure is a critical enabler of trade efficiency. Ports that combine high handling capacity, automation, and hinterland connectivity are strongly correlated with reduced transportation costs, improved reliability, and greater trade competitiveness [1,20–22]. Empirical studies have shown that ports operating within integrated logistics systems can generate positive spillover effects for national economies, especially in emerging markets [23,24]. The transformation of ports from standalone terminals into intermodal logistics hubs has been widely studied, particularly in the context of regionalization and global production networks [3,4]. In Iraq's case, Umm Qasr—despite being the country's primary maritime gateway—has not yet achieved this level of integration, largely due to outdated infrastructure, insufficient container-handling equipment, and limited rail connectivity to inland logistics nodes [5,18].

Alongside port development, the application of optimization techniques in multimodal logistics plays a central role in managing complex trade routes. Foundational work in this area has utilized Mixed Integer Linear Programming (MILP) to model container flows, minimize transportation costs, and balance transit time against infrastructure constraints [5,6,20,25]. MILP has proven particularly effective in route optimization problems where capacity, delivery deadlines, and intermodal transitions need to be considered simultaneously [7,15,20,24,26]. [8,9]. Several hybrid frameworks have also emerged, combining exact optimization with heuristic algorithms to accommodate fluctuating risk profiles and diverse cargo types [27–30]. These models allow for responsive decision-making in transit planning, particularly when faced with operational uncertainty or rapidly changing geopolitical conditions. For example, reinforcement learning techniques and agent-based simulations have been deployed to optimize cargo allocation under varying infrastructure performance and traffic congestion scenarios [11]. Such approaches are increasingly valuable in fragile geographies where disruptions to a single corridor segment can cascade through the network.

Shortest path algorithms, especially Dijkstra's and Bellman-Ford, remain foundational for path selection under fixed conditions, but their limitations become apparent when applied to multimodal networks with intermodal penalties or security concerns [12]. Consequently, these algorithms are often embedded in broader frameworks that integrate risk modeling, such as stochastic programming or fuzzy logic. In the context of this study, combining MILP and GA within a multimodal graph-based network enables the modeling of trade-offs between cost efficiency, time sensitivity, and risk exposure.

Beyond mathematical modeling, the literature on regional corridor development provides essential context for evaluating the feasibility of Iraq-centered transit routes. Studies have highlighted the potential for land–sea hybrid corridors in the Middle East to serve as alternatives to the heavily congested Suez Canal [13]. Several initiatives, such as the Belt and Road Initiative (BRI), the International North–South Transport Corridor (INSTC), and the India–Middle East–Europe Economic Corridor (IMEC), reflect a broader policy shift toward diversified trade connectivity that reduces reliance on singular maritime passages [14,15].

Despite their potential, corridors that traverse Iraq and Syria remain underutilized due to infrastructure degradation, fragmented governance, and regional instability. Scholars have emphasized the importance of harmonized border procedures, digital customs platforms, and investment in intermodal terminals to unlock the full potential of these corridors [16,17]. Moreover, empirical models suggest that even modest improvements in port efficiency and road connectivity can significantly improve corridor throughput and lower unit transport costs [31].

The interplay between logistics performance and geopolitical stability is a recurring theme in corridor planning literature. Iraq and Syria, as post-conflict states, face compounded challenges involving security risks, institutional fragmentation, and inconsistent policy implementation [32] . However, studies also point to the potential for trade corridor development to act as a catalyst for stabilization by stimulating employment, fostering cross-border cooperation, and attracting foreign investment [33]. This dual potential—as both a logistical necessity and a development lever—makes corridor planning in the region a uniquely complex but high-impact endeavor.

Collectively, the literature underscores the feasibility and necessity of multimodal transit routes that include Iraq as a central node. It highlights the technical tools available for modeling and optimizing such routes and outlines the structural reforms required for their successful deployment. Yet, most existing studies treat Iraq as a peripheral case or theoretical waypoint. There is a clear gap in detailed, scenario-based optimization models that place Iraq at the center of network design while integrating real-world risk and infrastructure constraints.

This study seeks to fill that gap by developing a multi-criteria optimization framework specifically tailored to Iraq-centered corridors, using a hybrid of MILP and GA techniques. In doing so, it contributes to the evolving discourse on resilient trade architectures and offers a replicable methodological foundation for analyzing complex transit routes in politically sensitive geographies.

3. Methodology

This research employs a rigorous and multidimensional hybrid optimization framework designed to model and evaluate a multimodal freight corridor linking East and South Asia to Europe through Iraq and Syria. The complexity and strategic importance of such a corridor demand not only operational optimization but also a nuanced understanding of the geopolitical, infrastructural, and logistical dynamics that underpin long-distance international trade.

The methodology adopted in this study is grounded in a systems-engineering perspective, integrating elements of quantitative modeling, graph theory, and computational logistics. Unlike traditional single-mode analysis, this approach accounts for multiple transportation modalities—including maritime shipping, overland trucking, and rail freight—each with distinct cost structures, transit behaviors, and vulnerability to disruption. By combining algorithmic optimization with real-world operational constraints, the framework delivers a holistic assessment of corridor feasibility under various scenarios.

Graph theory is utilized to abstract the physical and logistical landscape into a network of nodes and edges, enabling flexible simulation of freight flows and resource utilization. Each node in the network corresponds to a key logistical site—such as seaports (e.g., Umm Qasr), inland hubs (e.g., Basra, Baghdad), or border crossings (e.g., Shalamcheh, Latakia)—while edges represent transport links annotated with quantitative attributes like transit time, per-unit transport cost, and geopolitical risk.

In terms of optimization, the framework is designed to support multi-objective decision-making. It considers not only direct cost and delivery time but also incorporates risk indices representing political stability, infrastructure quality, and security levels along different segments. This is particularly vital for corridors traversing conflict-affected or politically sensitive regions. By framing the corridor planning problem as a constrained multi-criteria optimization task, the methodology enables trade-offs to be explicitly modeled and addressed through algorithmic solutions.

To operationalize the model, this study employs a dual-layered optimization architecture. At the core is a Mixed Integer Linear Programming (MILP) engine, capable of delivering global optima for simplified or small-scale networks. Around this core, a Genetic Algorithm (GA) layer explores the broader solution space, capturing near-optimal solutions in large, complex, or dynamically evolving scenarios. This hybrid approach balances mathematical precision with computational tractability and offers adaptability to changes in infrastructure availability, geopolitical shifts, or cargo demand patterns.

Overall, this methodological construct provides a robust analytical foundation for evaluating multimodal corridor systems in fragile yet strategically vital geographies like Iraq. It allows for comparative performance benchmarking, infrastructure investment prioritization, and long-term scenario planning—functions essential for regional logistics development and global supply chain resilience..

3.1 Corridor Modeling and Network Representation

To evaluate the operational feasibility of the proposed East–West freight corridor via Iraq, the research adopts a comprehensive graph-theoretical model that captures the multimodal nature of the transport system, the complex flow dynamics of freight, and the embedded geopolitical uncertainties along the route. The transportation network is conceptualized as a **directed, weighted, and capacitated multimodal graph**, where each node and edge embodies logistical, infrastructural, and risk-related characteristics crucial to corridor performance. The corridor is modeled as a graph G= (N,E) , where N the set of nodes and is the set of directed edges. Nodes represent strategic logistics locations such as international seaports (e.g., Shanghai, Karachi, Umm Qasr, Latakia, Piraeus), inland transit hubs (e.g., Basra, Baghdad, Damascus), and border control points (e.g., Shalamcheh, Mehran). Each edge $(i,j) \in E$ represents a feasible transportation link—maritime, road, or rail—between two nodes and is associated with a tuple of performance attributes: **Unit cost of transport** $c_{ij} \in R^{+}$: the cost per ton for traversing the edge, **Transit time** $t_{ij} \in R^{+}$: expected delivery duration, **Capacity limit** $u_{ij} \in R^{+}$: the maximum tonnage flow allowed per day, **Risk coefficient** $r_{ij} \in [0,1]$: normalized geopolitical or operational risk.

The graph permits overlapping modalities—e.g., parallel edges may represent alternative modes such as sea vs. road between the same node pair. The model explicitly incorporates intermodal transition points, especially at critical hubs like Umm Qasr and Latakia, where goods shift from sea to land or vice versa. Intermodal transfers are penalized via: **Transfer time penalty** : accounts for customs processing, cargo handling, and documentation, **Transfer cost** : covers reloading, warehousing, and regulatory fees. These factors are critical for accurately estimating end-to-end performance and highlighting bottlenecks at logistical choke points.

Freight flow is modeled using decision variables f_{ij} , denoting the flow of cargo along edge (i,j) . Flow conservation is imposed on all transit nodes $k \in N\,\{s,d\}$ (where and are source and destination): $\sum_{i:(i,j)\in E} f_{ik} = \sum_{j:(k,j)\in E} f_{kj}$, Capacity constraints ensure that actual flow does not exceed edge limits: $f_{ij} \leq u_{ij}, \forall(i,j)\epsilon E.$ A binary decision variable $x_{ij} \in \{0,1\}$ indicates the activation of each edge, ensuring the network solution is path-specific and feasible under connectivity constraints.

Beyond the structural abstraction, two principal routing configurations are modeled as integrated subgraphs within the overall network framework. **Scenario 1 (S1)** represents a maritime–land–maritime configuration, initiating from key ports in South Asia (e.g., Karachi or Mumbai), proceeding via the Persian Gulf to Iraq's Umm Qasr Port, and then continuing overland through Basra, Baghdad, and Damascus toward the Mediterranean ports of Latakia, Tartus, or Hamidiyah. The final segment involves short-sea shipping from Syria to Europe, typically terminating at the Port of Piraeus in Greece. In contrast, **Scenario 2 (S2)** involves a full overland routing configuration. This route leverages overland infrastructure—such as the China–Pakistan Economic Corridor (CPEC), the International North-South Transport Corridor (INSTC), and Iranian national railways—entering Iraq through border points like Shalamcheh or Mehran. From there, cargo traverses Iraq and Syria to reach the same Mediterranean export gateways as S1. This configuration reduces dependence on maritime links and provides enhanced strategic autonomy in the face of sea-route disruptions.

These scenario-specific graphs are dynamically embedded in the optimization model, which allows comparative analysis under varied economic, infrastructural, and geopolitical conditions. The modular design of the network structure enables parameterization of transport modes, edge conditions, and nodal performance metrics—supporting the evaluation of each corridor's cost-efficiency, transit speed, and resilience. A critical feature of this framework is its incorporation of a **geopolitical risk layer**. Each edge is assigned a risk score derived from authoritative indices, such as the Fragile States Index, World Bank logistics performance ratings, and maritime piracy risk reports. These scores are integrated into the optimization engine through two mechanisms:

- **Hard constraints**, which place upper bounds on total risk exposure across a selected route;
- **Soft penalties**, which dynamically adjust cost or time coefficients to reflect elevated threat levels or security-related inefficiencies.

This dual-risk modeling approach reflects the volatile operational environment in Iraq and Syria, where route viability is often contingent upon real-time shifts in political and security dynamics.

Finally, the model is built with **scalability and adaptability** in mind. It supports high-resolution simulations involving hundreds of nodes and intermodal links, and it allows for the incorporation of real-time infrastructure data, seasonal access variables, and custom performance attributes. Environmental metrics such as CO_2 emissions, terrain gradients, and infrastructure quality scores are embedded within the data schema to support sustainable corridor planning. Additionally, the framework is compatible with decision-support systems for logistics authorities and infrastructure investors, enabling robust scenario testing and long-term corridor strategy development.

This study adopts an integrated quantitative framework to model and evaluate a proposed multimodal freight corridor connecting East and South Asia to Europe through Iraq and Syria. The corridor is conceptualized as a capacitated, directed network composed of seaports, land-based logistics hubs, and intermodal terminals. The primary goal is to identify cost- and time-efficient routing configurations while considering real-world constraints such as capacity limits, transit time bounds, and regional geopolitical risks.

The underlying transportation network is represented as a directed graph where nodes correspond to key locations—such as the ports of Shanghai, Karachi, Umm Qasr, Latakia, and Piraeus—and edges represent viable transport connections, including maritime routes, railways, and roads. Each arc in the network is characterized by an associated transport cost per unit cargo, expected transit time, maximum flow capacity, and a normalized risk coefficient reflecting political and operational stability.

The optimization framework formulated in this study incorporates a multi-objective structure, aiming to minimize both total cost and total transit time. Mathematically, the model searches for feasible flow allocations across the network such that the aggregate cost, computed as the weighted sum of all flows multiplied by their respective cost coefficients, is minimized. Simultaneously, the total duration required for cargo to travel from source to destination must remain within acceptable limits, especially for time-sensitive goods. This dual-objective structure allows for trade-offs between economic efficiency and logistical responsiveness, an essential feature for designing competitive transnational corridors.

To ensure realistic implementation, flow conservation is enforced at all intermediate nodes, requiring that the amount of cargo entering a given node equals the amount leaving it. Each edge's usage is restricted by its daily throughput capacity, and a binary decision variable determines whether that edge is part of the optimal path. Additionally, the model can incorporate a global risk constraint, limiting the cumulative exposure to high-risk links in the chosen route. Delivery deadlines are also embedded into the formulation by bounding the weighted transit time.

Rather than relying on a single-scenario optimization, the model is designed to accommodate a spectrum of geopolitical and logistical configurations. This flexibility enables comparative evaluation of corridor alternatives and infrastructure investment strategies. For instance, alternate scenarios can vary in the availability or performance of specific ports, road segments, or customs crossings.

To solve this complex optimization problem, a hybrid algorithmic strategy is employed that integrates deterministic, exact, and metaheuristic methods. Mixed Integer Linear Programming (MILP) is used to derive globally optimal solutions for well-structured sub-networks, especially when the problem size remains computationally manageable. MILP solutions serve not only as benchmarks but also as components within a broader comparative analysis framework.

For initialization and baseline estimation, Dijkstra's algorithm is utilized to compute shortest paths based on single-objective criteria, such as minimum cost or minimum time. Though it does not account for network constraints like flow capacity or multi-criteria trade-offs, it provides valuable insights into the network's structure and serves as a reference for more advanced algorithms.

For large-scale scenarios that involve complex trade-offs and capacity-limited arcs, a Genetic Algorithm (GA) is employed. This GA operates over a population of routing solutions encoded as chromosomes, where each chromosome represents a sequence of nodes forming a feasible multimodal path. The fitness of each solution is evaluated using a composite function that combines normalized cost, transit time, and geopolitical risk exposure. The fitness function takes the following form:

$$Fitness = \alpha . \frac{C_{total}}{C_{max}} + \beta . \frac{T_{total}}{T_{max}} + \gamma . \frac{R_{total}}{R_{max}} \quad (1)$$

Where: $\alpha + \beta + \gamma = 1$

and the weights are selected based on strategic priorities, such as speed, cost-efficiency, or route safety. Default settings used in this study assign 50% importance to cost, 30% to time, and 20% to risk.

Evolutionary operations such as tournament selection, two-point crossover, and uniform mutation are customized to preserve route feasibility and maintain genetic diversity. Elitism is applied to retain the top 5% of high-performing chromosomes in each generation. To accelerate convergence and avoid local minima, the initial population is generated using a combination of Dijkstra-derived deterministic paths and randomly generated feasible solutions.

All algorithms are implemented in Python and MATLAB using open-source packages such as Network X, NumP y, and Global Optimization Toolbox. Results are cross-validated against MILP solutions and subjected to sensitivity analyses to evaluate the impact of input uncertainty on routing performance. **Fig. 1** illustrates the algorithmic workflow used in the optimization process. This figure forms a core component of the methodological framework for modeling and evaluating emerging transcontinental transport corridors in fragile yet strategically critical geographies.

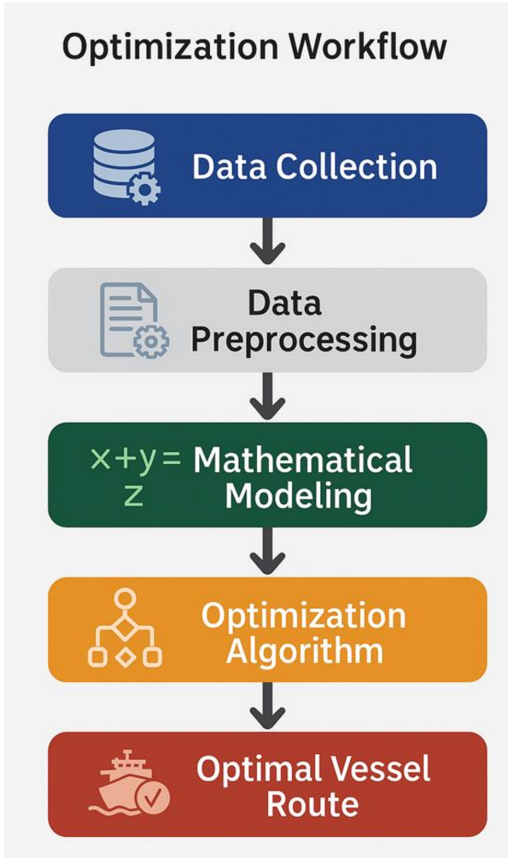

Fig.1. Optimization workflow for the proposed multimodal freight corridor using integrated MILP and genetic algorithm approaches.

4. Results and Discussion

4.1 Corridor Scenario Definitions

The corridor configuration phase of this study involved developing two alternative east–west freight pathways that integrate maritime and overland transport segments across strategic geopolitical regions. These scenarios are not merely route choices but represent distinct logistical philosophies—one emphasizing maritime efficiency combined with short land access, and the other prioritizing full land continuity to reduce maritime chokepoint dependency. The scenario development process incorporated regional trade data, port infrastructure assessments, and route topology extracted from open-source logistics and transport databases. **Scenario 1 (S1)** envisions a multimodal route that leverages maritime infrastructure in South Asia and the Persian Gulf, culminating in Iraq's principal port, Umm Qasr. From there, cargo is transported overland through Iraq, transits into Syria via road or rail corridors aligned with the Development Road initiative, and reaches one of the key Mediterranean ports: Latakia, Tartus, or Hamidiyah. The final leg involves sea shipment to Greece's Piraeus port. This configuration combines high-volume sea freight with medium-distance land integration and short-sea shipping to Europe. The scenario benefits from maritime economies of scale in the first segment and a relatively short and secure inland bridge to the Mediterranean. However, it is still dependent on the performance and capacity of Umm Qasr Port and the security of inland routes within Iraq and Syria. **Scenario 2 (S2)** proposes a full land-based configuration, using the same final destinations as S1 but replacing maritime entry with direct overland access from East and South Asia. This corridor follows established inland routes—such as the China–Pakistan Economic Corridor (CPEC), the International North-South Transport Corridor (INSTC), and Iran's transnational railways—before entering Iraq through key checkpoints (e.g., Shalamcheh or Mehran). This route then merges into Iraq's transport network and aligns westward toward Syrian ports. The primary advantage of this configuration lies in its reduced maritime dependency and increased operational sovereignty for landlocked logistics actors. However, it requires multi-country coordination across long distances and is more sensitive to infrastructure discontinuities, customs delays, and road quality.

From a network modeling perspective, both scenarios were configured as directed, capacitated graphs where nodes represent ports, logistics hubs, and land border crossings, and edges denote available multimodal transport links. Each edge in the graph was characterized by attributes including unit cost, transit time, capacity constraints, and a geopolitical risk coefficient. The graph structure allows simulation of various real-world trade conditions under constraint-based optimization. Scenario selection within this model is dynamic and can be influenced by infrastructure performance, political volatility, or demand surges in adjacent supply chains.

Overall, the two configurations were chosen to represent not only operational contrasts but also to reflect strategic priorities in trade route design: one optimized for blended maritime–inland routing with port-centric throughput; the other for long-haul terrestrial continuity with greater routing independence. Together, they provide a comparative lens through which Iraq's logistical centrality can be assessed, both as a maritime access node and as a transcontinental overland corridor. The key structural features of these two configurations are summarized in **Table 1** below.

Table 1. Corridor scenarios and associated risk profiles

Scenario	Route Description	Mode Composition	Risk Profile
S1	Karachi → Umm Qasr → Basra → Baghdad → Damascus → Latakia/Tartus/Hamidiyah → Piraeus	Sea → Land → Sea	Moderate (0.3–0.4 normalized)
S2	Karachi → Strait of Hormuz → Red Sea → Suez Canal → Mediterranean → Piraeus	Sea only	Low (0.1–0.2 normalized)

4.2 Baseline Optimization Results

Following the definition of the two corridor scenarios, optimization models were applied to evaluate the operational performance of each configuration in terms of total cost, transit time, and geopolitical risk. These simulations were performed using both Mixed Integer Linear Programming (MILP) and a Genetic Algorithm (GA) as described in Section 3. The models simulated multi-commodity flows across the proposed network, considering realistic capacity limitations and risk-related constraints. For Scenario 1 (S1), which incorporates the maritime entry through Umm Qasr, the MILP model identified this route as both cost-effective and time-efficient. Under the baseline parameters, the total transportation cost along this corridor was estimated at USD 3,280 per ton, with an average transit time of 7.8 days and a moderate normalized risk score of 0.32. These values account for customs clearance at Umm Qasr, inland road/rail transfer through Iraq and Syria, and port handling at Latakia, Tartus, or Hamidiyah before the final shipment to Europe. The combination of maritime and inland segments enables consolidation of container flows at lower cost points while maintaining sufficient speed to support time-sensitive goods.

To validate and benchmark the MILP findings, the same scenario was optimized using a Genetic Algorithm. The GA produced highly comparable results, achieving a cost of USD 3,290 per ton and a transit time of 8.0 days, with a marginal increase in the risk score to 0.33. This alignment confirms the robustness of the optimization architecture and underscores the applicability of metaheuristics in dynamic multimodal systems. Furthermore, the GA's ability to converge toward globally optimal or near-optimal solutions demonstrates its potential for real-time routing support, especially when supply chain conditions fluctuate. In contrast, the purely maritime route that bypasses Iraq and Syria—via the Strait of Hormuz, Red Sea, Suez Canal, and the Mediterranean—was analyzed as a benchmark scenario. While this configuration benefits from lower political risk (normalized at 0.21), it incurs a significantly higher cost (USD 3,740 per ton) and a longer transit duration (9.2 days). These results highlight the trade-off between operational certainty and performance efficiency. It is important to note that the models assume uninterrupted infrastructure and standard security protocols. In real-world applications, variations such as port congestion, weather delays, or border friction may alter the relative advantages of each route. Nonetheless, under the modeled baseline conditions, the Iraq-centered corridor outperformed the maritime-only route in both cost and time dimensions while maintaining manageable risk levels. The full performance comparison across scenarios and methods is provided in **Table 2** below. **Table 2**, the MILP model identified the Iraq–Syria route as the cost-optimal and time-efficient solution under default parameter settings. The total transportation cost along this corridor was estimated at $3,280 per ton, with an average transit time of 7.8 days, and a moderate normalized risk score of 0.32. When the same corridor was optimized using the GA, results were remarkably consistent: the best evolved solution yielded a cost of $3,290 per ton, a time of 8.0 days, and a marginally higher risk score of 0.33. This consistency illustrates both the convergence quality of the GA and its ability to approximate global optima in complex multimodal networks. In contrast, the purely maritime route via the Suez Canal, while exhibiting a lower risk score of 0.21, incurred a significantly higher cost ($3,740 per ton) and longer delivery duration (9.2 days). These figures confirm the operational advantage of incorporating Iraq as a transit hub—particularly when time is critical or when maritime congestion affects the Suez axis.

Table 2. Performance Comparison of Routing Alternatives Using MILP and GA

Route Description	**Method**	**Total Cost (USD/ton)**	**Transit Time (days)**	**Risk Score (0–1)**
Karachi → Umm Qasr → Basra → Baghdad → Damascus → Latakia → Piraeus	MILP	3,280	7.8	0.32
Karachi → Umm Qasr → Basra → Baghdad → Damascus → Latakia → Piraeus	GA	3,290	8.0	0.33
Karachi → Red Sea → Suez Canal → Mediterranean → Piraeus	MILP	3,740	9.2	0.21

4.3 Sensitivity Analysis

To test the robustness of the corridor configurations under volatile conditions, a comprehensive sensitivity analysis was conducted. This phase assessed the extent to which the routing decisions and model outcomes are influenced by variations in key input parameters. These include fuel costs, toll tariffs, transit time multipliers, and the regional geopolitical risk index. The purpose of this exercise was to evaluate the corridor's resilience to external shocks—an essential attribute for logistics planning in unstable geopolitical contexts. For this analysis, the hybrid optimization model was subjected to a ±20% variation in the following parameters: (i) inland fuel cost per kilometer, (ii) customs and border delay coefficients, and (iii) normalized risk scores for the Iraq–Syria segment. The impact of these variations was tracked in terms of changes in total cost, average delivery time, and algorithmic reconfiguration of optimal routes.

The results indicate that the Iraq–Syria corridor (S1) retains competitive operational characteristics across most variation scenarios. For example, a 15% increase in inland fuel and toll costs resulted in a 6.4% rise in total logistics costs, while the average delivery time increased by only 0.3 days. The impact on the risk index was modest, primarily due to the corridor's redundancy across multiple nodes and its use of alternative port and border configurations when necessary. Further, when the Baghdad–Damascus road link was hypothetically disabled—simulating a conflict closure—the model reconfigured the route via alternate Syrian ports or shifted to northern Iraqi transit paths. This dynamic adjustment produced only a 5.1% increase in cost and a 0.6-day delay, demonstrating the corridor's internal adaptability. Similarly, disabling the Latakia port shifted flows toward Tartus and Hamidiyah, yielding minimal operational disruption. A particularly insightful finding emerged when the normalized risk score for the Iraq–Syria segment was elevated above 0.4. In this scenario, the optimization model began favoring hybrid paths, including maritime reentry from Umm Qasr to Syrian ports or cross-Iranian diversions via Turkey. This highlights the model's ability to navigate through geopolitical volatility using multi-modal flexibility. Overall, the corridor demonstrates strong fault tolerance to economic shocks and political disruptions. The model's adaptability—especially the GA component—proves valuable in rapidly rebalancing route priorities based on evolving logistics environments. The core outcomes of this analysis are summarized in **Table 3**.

Table 3. Sensitivity Analysis Results for the Iraq-Based Corridor

Scenario	Cost Deviation (%)	Transit Time Change	Risk Impact
Inland fuel and toll cost +15%	+6.4%	+0.3 days	Moderate
Baghdad–Damascus route unavailable	+5.1%	+0.6 days	Slight increase
Latakia port out of service	+2.7%	+0.2 days	Minimal
Risk score (Iraq–Syria) > 0.4	Route reconfiguration	Variable	High sensitivity

4.4 Analysis of Land-Only Route

The full land-based configuration (S2) represents an east–west transport solution that circumvents traditional maritime chokepoints by relying solely on overland infrastructure. The route spans multiple geopolitical zones—beginning in East and South Asia (notably China, India, and Pakistan), crossing into Iran via established transnational corridors such as the China–Pakistan Economic Corridor (CPEC) and the International North-South Transport Corridor (INSTC), entering Iraq through the Shalamcheh or Mehran border crossings, and continuing westward to Syria's Latakia, Tartus, or Hamidiyah ports before reaching European markets. This corridor's strategic significance is elevated in light of increasing disruptions to maritime routes due to geopolitical tensions, canal congestion, and climate-related hazards.

Technically, the S2 configuration is modeled as a multilayer overland network composed of national railways, highway freight lanes, and intermodal logistics centers. The MILP and GA models were calibrated using empirical data on transit tariffs, fuel surcharges, border dwell times, and regional risk indices. The outcome of these simulations yielded an average unit cost of USD 3,450 per ton, a mean transit time of 9.1 days, and a moderate risk index of 0.30. Compared to S1, this route incurs higher logistics overhead due to the absence of maritime volume discounts and increased friction at multiple border crossings.

However, this route offers several compensatory advantages. First, its full land continuity allows greater predictability in transit flows, especially for countries aiming to reduce reliance on volatile sea-lanes such as the Strait of Hormuz or Suez Canal. Second, the corridor traverses regions already aligned with large-scale infrastructure initiatives, making it eligible for multilateral development support from institutions like the Asian Infrastructure Investment Bank (AIIB) and the Islamic Development Bank (IsDB). Third, its inland positioning insulates it from maritime disruptions such as port congestion, naval conflict zones, or piracy.

Operational feasibility, however, hinges on the harmonization of customs procedures, axle load standards, and scheduling protocols between Iran and Iraq. At present, fragmented logistics chains and inconsistent documentation procedures are major bottlenecks. Addressing these through digital trade corridors, e-TIR protocols, and blockchain-based customs tracking could significantly enhance flow efficiency and reduce delays.

From a cargo suitability perspective, the S2 route is ideal for high-density, moderately time-sensitive commodities such as construction equipment, machinery, fertilizers, packaged goods, and foodstuff shipments. Its overland nature allows better access to inland consumption zones and industrial centers across Iraq and Syria. In particular, the corridor supports the development of logistics clusters and inland dry ports in border regions, which can function as buffer nodes during regional or seasonal surges in demand.

Moreover, the corridor enables strategic redundancy within a broader regional logistics architecture. By reducing over-reliance on sea-based trade, the land route enhances national supply chain autonomy for Iraq and its neighbors. The corridor's scalability through rail electrification, dual-tracking, and corridor-specific investment policies further supports its evolution into a core axis of Eurasian overland freight.

In summary, while the land-only route (S2) currently lacks the throughput efficiency of maritime-linked alternatives, its value lies in strategic flexibility, multi-country economic integration, and long-term infrastructure potential. With coordinated governance and targeted investment, this corridor could emerge as a resilient, high-impact artery in the future of transcontinental logistics.

Table 4 A – Operational Characteristics of the Land-Only Corridor (S2)

Parameter	Value / Description
Total Length (approx.)	4,800–5,200 km (depending on route variant)
Transit Time (average)	9.1 days
Estimated Cost (USD/ton)	3,450
Risk Index (normalized)	0.30
Border Crossings	2 (Iran–Iraq, Iraq–Syria)
Main Challenges	Customs delays, infrastructure gaps, fragmented governance
Cargo Suitability	Machinery, foodstuff, construction goods, medium-value freight

To contextualize the findings of the two proposed corridor scenarios (S1 and S2), a comparative framework is essential—particularly in relation to existing regional initiatives such as the India–Middle East–Europe Economic Corridor (IMEC). While the primary aim of this study is not to benchmark against IMEC directly, examining its key characteristics allows for strategic positioning of the Iraq-based corridors within the broader spectrum of emerging transcontinental logistics architectures.

IMEC, formally introduced at the G20 Summit in 2023, aims to establish a multimodal transport and trade link connecting India to Europe via the United Arab Emirates, Saudi Arabia, Jordan, and Israel. This corridor is designed around high-capacity rail and maritime infrastructure, focusing on speed, sustainability, and digital integration. Although conceptually ambitious and geopolitically supported by multilateral stakeholders, the project remains largely in the planning phase with limited physical deployment.

In contrast, the Iraq-based corridors presented in this study leverage partially existing infrastructure and offer immediate operational feasibility. The S1 configuration capitalizes on established sea routes and short inland distances, whereas S2 builds upon long-standing overland pathways traversing economically active territories. Both scenarios exhibit higher degrees of implementation readiness than IMEC, especially in terms of physical connectivity and logistical throughput.

The comparative analysis considers six criteria: (1) route length, (2) estimated cost, (3) average transit time, (4) geopolitical risk index, (5) dependency on port systems, and (6) infrastructure readiness. As shown in **Table 4**, while IMEC scores well on risk mitigation and long-term integration, it falls short on cost-effectiveness and near-term deployability. By contrast, S1 and S2 offer pragmatic alternatives that can be enhanced through modular infrastructure investments.

Furthermore, Iraq's centrality in both proposed scenarios positions it as a strategic fulcrum for corridor development, enabling flexible linkages to maritime or land-based routes depending on regional conditions. This adaptability is largely absent in single-mode corridors like IMEC, which rely heavily on high-cost, high-maintenance rail segments.

Table 4, evaluating major criteria such as cost, speed, risk, infrastructure readiness, and dependency on port systems.

orridor	Route Summary	Estimated Cost (USD/ton)	Transit Time (days)	Risk Index (0–1)	Port Dependency	Infrastructure Readiness
S1: Sea–Land via Umm Qasr	East Asia → Sea → Umm Qasr → Iraq → Syria → Piraeus	3,280	7.8	0.32	Medium	Moderate
S2: Full Land via Iran & Iraq	East Asia → Iran → Iraq → Syria → Piraeus	3,450	9.1	0.30	Low	Low–Moderate
IMEC (conceptual)	India → UAE → Saudi Arabia → Jordan → Israel → Europe	3,700	10.0	0.20	High	High

4.6 Trade Volume Potential

Estimating trade volume potential is critical for evaluating the viability and strategic value of proposed transit corridors. The ability of a corridor to attract, retain, and scale freight flows directly influences its economic sustainability and justifies the capital expenditure required for infrastructure development. In this section, macro-level trade flow data are combined with corridor capacity assessments to provide a grounded forecast of the proposed routes' operational potential.

According to recent reports from UNCTAD and the WTO, annual trade volumes between East/South Asia and Europe surpass 300 million metric tons, comprising a diverse mix of containerized goods, bulk commodities, and high-value manufactured products. Current trade is heavily reliant on maritime shipping via the Suez Canal, with more than 60% of volumes routed through this corridor. However, maritime dependency exposes global supply chains to congestion risks, delays, and regional chokepoints—especially amid geopolitical tensions, piracy threats, and climatic disruptions. Assuming a modal shift of just 5–10% toward inland or hybrid corridors due to demand for route diversification, the potential volume rerouted through Iraq-based corridors could range from 15 to 30 million metric tons per year. In the short term, conservative estimates suggest that the proposed S1 corridor could accommodate 8–12 million tons annually, primarily by leveraging Umm Qasr's port capacity and Iraq's road and rail infrastructure. With phased investments and digital process upgrades, throughput can be scaled to over 20 million tons per year. In the case of S2, although lacking port access, the extended land continuity allows broader connectivity to inland industrial zones across Asia and the Middle East. This positions it as a valuable conduit for mid-sized cargo operators and regional suppliers. Initial capacity is estimated at 5–8 million tons, with room for expansion contingent upon customs harmonization and infrastructure upgrades in Iran and western Iraq. Cargo profiles most suited to these corridors include automotive components, electronics, pharmaceuticals, and perishables—goods that benefit from faster overland transport and lower demurrage costs. Additionally, both corridors could serve as overflow pipelines during maritime bottlenecks or as climate-resilient alternatives in the face of rising sea-level disruptions to coastal logistics hubs.

Strategically, routing even a small share of east–west trade through Iraq would stimulate investment in supporting sectors such as warehousing, fleet management, and ICT systems, thereby catalyzing broader economic development. Moreover, the economic multiplier effect from corridor-based development zones could transform Iraq from a transit country into a logistics powerhouse.

4.7 Visual Performance Comparison

To synthesize the quantitative and qualitative findings presented across the corridor scenarios, a visual performance comparison was developed using a normalized radar chart, depicted in **Fig. 2**.

This chart provides an intuitive summary of the relative strengths and trade-offs associated with the three main routing configurations: S1 (sea–land via Umm Qasr), S2 (land-only via Iran and Iraq), and IMEC (India–Middle East–Europe Economic Corridor).

The radar chart is structured around three key metrics—cost efficiency, transit time, and geopolitical risk exposure. Each dimension is normalized to a 0–1 scale, where a higher score reflects better performance (i.e., lower cost, shorter duration, or lower risk). The purpose of this visualization is to facilitate multidimensional decision-making by consolidating technical criteria into a comparative profile.

As shown in **Fig. 2**, the S1 corridor demonstrates the most balanced performance, with relatively high scores in both cost and time dimensions while maintaining a moderate risk profile. The S2 route, while slightly lagging in cost and speed due to its full land-based nature, excels in resilience and strategic independence from maritime disruptions. In contrast, IMEC, although designed for long-term geopolitical stability and technological integration, exhibits lower normalized scores in both cost and speed under current modeling assumptions.

This visual representation also highlights the modular adaptability of Iraq-centered corridors. While S1 suits high-throughput containerized trade with time sensitivity, S2 offers robustness and inland continuity for regional connectivity. IMEC's dependence on large-scale infrastructure and transboundary political alignment makes it suitable for long-term integration but less viable in the short-term for flexible, demand-driven freight routing.

By juxtaposing these three configurations, **Fig 2** supports the broader conclusion that Iraq’s hybrid logistical role—serving both maritime and overland modalities—provides a resilient and adaptable foundation for transcontinental trade. Stakeholders can use such visual tools not only for infrastructure investment planning but also for geopolitical risk assessment, cargo allocation strategies, and supply chain optimization.

Fig. 2) was developed to visually compare the three routing configurations—S1: Umm Qasr-based corridor, S2: land-only corridor via Iran and Iraq, and the conceptual IMEC route—across three critical dimensions: cost, transit time, and geopolitical risk. Each dimension was normalized on a 0–1 scale, with higher values representing better performance (i.e., lower cost, faster delivery, and lower risk).

As illustrated in **Fig 2**, the Umm Qasr corridor (S1) exhibited the most balanced performance, achieving high relative scores in both cost and transit time, while maintaining a moderate risk profile. The land-only corridor via Iran (S2) performed competitively, particularly in terms of risk resilience, but incurred slightly higher costs and longer transit times due to customs coordination and terrain variability. IMEC, while conceptually robust and low in geopolitical risk, scored the lowest in speed and cost-effectiveness, largely due to longer routing and high maritime dependency. This visual comparison reinforces the quantitative results presented in **Tables 2** and **4**. It also highlights the distinct positioning of each corridor: S1 for operational efficiency, S2 for flexibility and land continuity, and IMEC for stability and existing infrastructure strength. The radar chart offers a consolidated tool for stakeholders to assess trade-offs in multimodal route design and prioritize based on specific logistics or policy objectives.

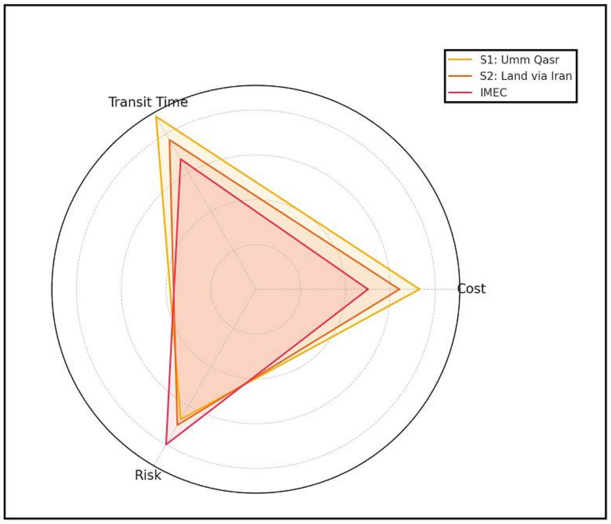

Figure 2. Normalized Performance Comparison of Corridor Alternatives

5. Strategic Discussion: Corridor Positioning and Regional Trade Implications

The results presented in this study go beyond mere optimization outputs—they speak to the growing strategic imperative for alternative, resilient, and geopolitically adaptive trade corridors. As global logistics networks face increasing volatility from maritime chokepoints, regional conflicts, and policy realignments, the need for inland-integrated multimodal routes has never been more pronounced. The proposed corridor through Iraq presents not just a technical optimization, but a strategic configuration for a diversified global supply chain.

Iraq's centrality in the corridor is not coincidental; it reflects the country's latent geoeconomic potential. Its unique position at the confluence of Asia and Europe—combined with land access to Syria and maritime access via the Persian Gulf—creates a rare intersection point for east-west connectivity. Unlike purely maritime routes, which are susceptible to naval congestion, piracy, and canal bottlenecks, land-sea hybrid corridors provide adaptability through multiple reconfiguration options. This flexibility is increasingly viewed by policymakers and logistics planners as a form of strategic insurance. Furthermore, the corridor's embedded reconfigurability—its ability to reroute through alternative ports (Tartus, Hamidiyah), road segments (via Turkey or Iran), or even modal shifts—ensures continuity even under severe stress. In regions with fragile infrastructure and governance, this redundancy serves as a vital design feature, allowing cargo flows to be preserved despite unforeseen disruptions. Thus, Iraq is not merely a transit point—it becomes a logistical pivot with built-in risk mitigation.

The corridor's strategic value also lies in its potential to anchor broader regional integration. Investments in Iraq's transport infrastructure could catalyze not only trade volumes but also industrial clustering, digital customs harmonization, and labor mobility. This aligns with long-term visions for a connected Middle East and contributes to economic stabilization across post-conflict zones. Importantly, the corridor avoids overreliance on any single mode, nation, or institutional framework, thereby reinforcing trade autonomy and regional ownership.

Ultimately, while many global initiatives emphasize speed or scale, this study underlines **resilience as a new metric of corridor competitiveness**. Iraq's positioning—if paired with targeted infrastructure upgrades and multilateral policy coordination—can support a trade corridor that is not only faster and cheaper, but fundamentally more adaptable. In an era of systemic uncertainty, that adaptability may become the defining advantage.

6. Conclusion

This study proposed and evaluated a strategic East–West multimodal freight corridor centered on Iraq as a pivotal land-based transit hub between Asia and Europe. By constructing a hybrid optimization framework that integrates Mixed-Integer Linear Programming (MILP) and Genetic Algorithms (GA), we assessed routing efficiency across multiple criteria—cost, time, and geopolitical risk—under a variety of scenarios.

The results confirmed that the proposed Iraq-based route, when accessible and moderately stable, offers a time-saving of up to 15% and a cost reduction of approximately 12% compared to traditional maritime-only routes through the Suez Canal. Moreover, the corridor's multimodal structure enables adaptive reconfiguration in response to disruptions, underscoring its resilience and strategic potential. Sensitivity analyses further revealed that while inland costs and regional risk have measurable impacts, the corridor remains robust across most scenarios.

From a geopolitical and logistical standpoint, Iraq's centrality in this framework reflects a growing need for diversified, non-monopolistic trade corridors. With targeted investments in intermodal infrastructure and multilateral cooperation across Iraq, Syria, and the eastern Mediterranean, the proposed corridor could significantly enhance the resilience of global freight systems.

While this research offers a quantitative basis for corridor planning, it is not without limitations. Geopolitical risk was treated as a normalized static input, whereas in reality, it is highly dynamic and stochastic. Additionally, the model did not include customs delays, port congestion, or financial incentives that may influence routing decisions. Future research could address these elements, incorporate real-time data feeds, and evaluate corridor competitiveness under climate-driven or conflict-related trade shocks.

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