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Multimodal Transport Supply Chain in China: An Integrated Analysis of Development Status and Optimization Framework

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Abstract:

As a core model integrating railway, road, waterway, and air transportation, the multimodal transport supply chain plays a critical role in improving logistics efficiency, reducing costs, and enhancing supply chain resilience. Against the backdrop of China's "domestic and international dual circulation" strategy and the deepening of the "Belt and Road Initiative", this paper explores the development status, existing problems, and optimization paths of China's multimodal transport supply chain. However, its development is constrained by several critical challenges that need to be addressed. Through a systematic analysis of policy documents, industry reports, and academic literature, this study finds that China has made phased progress in infrastructure construction, market scale expansion, and low-carbon exploration, but still faces three key dilemmas: market-legal-cost constraints, information-standard barriers, and regional imbalance-low-carbon obstacles. Corresponding suggestions are proposed: improving infrastructure and standard systems, and optimizing policy and legal mechanisms. The proposed framework and recommendations not only contribute to the theoretical discourse on integrated logistics management but also offer actionable insights for policymakers and logistics enterprises to enhance operational efficiency and competitiveness.

Keywords: Multimodal Transport; Supply Chain; Standardization; Low-Carbon Logistics; Interconnectivity

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1. Introduction

1.1 Research Background

In the modern logistics industry, the multimodal transport supply chain—serving as the core integration mode of railway, road, waterway, and air transportation—directly relates to national logistics efficiency and supply chain stability [1]. With the acceleration of global economic integration and supply chain reconstruction, multimodal transport has become a key support for optimizing industrial structures and enhancing national competitiveness. For China, which is in the critical period of economic transformation, developing multimodal transport is not only a practical need (2023 social logistics costs accounted for 14.4% of GDP) but also a strategic requirement to adapt to the "Belt and Road Initiative" and "domestic-international dual circulation" strategy.

China has issued supportive policies: the Ministry of Transport's Action Plan for Promoting the High-Quality Development of Rail-Water Intermodal Transport (2023-2025) clearly proposes to build a "railway-waterway-based, road-supplemented" network and raise the information interoperability rate of key nodes to over 80% by 2025. Up to now, national multimodal transport demonstration routes have been opened in 28 provinces, covering Beijing, Shanghai, Guangzhou, and other major comprehensive transport hub cities. However, there are still prominent challenges: railway and shipping enterprises use different data coding systems, resulting in low intermodal efficiency; many ports lack dedicated railway lines, leading to 24-48 hours of road-rail transfer time; the "dual division" of the Maritime Code and Contract Law causes legal application conflicts in cross-border transport; high transformation costs make it difficult for SMEs to apply intelligent and low-carbon academic models. These problems hinder high-quality development, requiring in-depth research. To address these challenges, substantial academic research has been conducted. However, a comprehensive framework that integrates the multifaceted nature of these problems is still lacking.

1.2 Literature Review

Relevant studies on multimodal transport mainly focus on operational optimization, legal mechanisms, and low-carbon development. This section summarizes 6 key literatures to clarify the research foundation and existing gaps.

He, He & Chi proposed a collaborative optimization model for container multimodal transport full-process paths and connecting truck scheduling [2]. Through empirical verification of Tianjin Port-Lanzhou dry port data, the model can reduce total operating costs by 5%-7.5% and shorten transport time by 10%-12%, but it ignores data barriers between transport enterprises, which this paper solves by exploring information-sharing mechanisms.

The Law School of Shanghai University of Finance and Economics analyzed 120 international multimodal transport dispute cases under the "Belt and Road Initiative" [3]. It found that the "dual division" of the Maritime Code and Contract Law prolongs the dispute handling cycle to 9 months (three times that of single-mode transport) and proposed a unified liability system, but lacked specific legislative paths, which this paper supplements with policy design.

Shen & Zong identified critical transport cities in China's multimodal transport network using PCA and stepwise regression [4]. Data from 31 provinces showed that East China cities (e.g., Shanghai) have multimodal transport scores 2.3 times higher than West China cities (e.g., Lanzhou), reflecting severe regional imbalance, but the study did not analyze root causes such as infrastructure gaps, which this paper explores.

Wei et al. used 2018-2023 panel data from 28 provinces to study the impact of multimodal transport on dual circulation [5]. The results showed that every 1% increase in multimodal transport volume drives 0.32% domestic circulation growth and 0.45% international circulation growth, confirming its economic value and noting that infrastructure and standards restrict its role—providing support for this paper's problem analysis.

International Transport Forum pointed out in the Multimodal Transport Efficiency Report that blockchain and IoT can improve information transparency, but only 15% of Chinese enterprises realize full-process data sharing due to inconsistent standards—reinforcing this paper's focus on information unification [6].

United Nations Conference on Trade and Development Transport that China's international multimodal transport lags Singapore and the Netherlands in customs efficiency, with cross-border time 30% longer—highlighting the urgency of legal optimization [7].

While the existing literature provides valuable insights into specific aspects of multimodal transport, it often operates in silos. The studies reviewed above tend to focus on isolated dimensions—be it operational efficiency, legal frameworks, or environmental impact—without adequately capturing their interconnectedness. This fragmented approach limits the ability to propose holistic solutions.

Existing studies lack multi-dimensional integration; this paper constructs a "market-legal-information-regional-technology" framework to fill this gap.

1.3 Research Objectives and Framework

This paper adopts deductive logic, with the following framework: First, it clarifies the research background and significance by analyzing the strategic role of multimodal transport and practical challenges, and sorts out theoretical gaps through a 6-study literature review. Second, summarize China's multimodal transport status from infrastructure (28-province routes), market scale, technology, and low-carbon development, using industry data for objectivity. Third, diagnose three core problems: market-legal-cost dilemmas, information-standard barriers, and regional imbalance-low-carbon obstacles. Fourth, propose targeted suggestions based on root causes, referring to international experience. Finally, summarize findings, clarify research value, and note limitations.

2. Developments and Achievements in China's Multimodal Transport Supply Chain

China's multimodal transport supply chain has achieved phased development results under policy guidance, laying a solid foundation for further high-quality development.

2.1 Infrastructure Construction

Significant strides have been made in infrastructure development, forming the physical backbone for multimodal transport. In terms of infrastructure construction, comprehensive freight hubs and connection nodes have advanced steadily. National multimodal transport demonstration routes have been opened in 28 provinces, basically covering national comprehensive transport hub cities and the main framework of the national comprehensive three-dimensional transport network [5]. These routes form a number of key corridors with regional characteristics, such as the Coastal Railway-Waterway Corridor connecting Shanghai Port with the Yangtze River Economic Belt, and the Inland Railway-Highway Corridor linking Chengdu-Chongqing with the Pearl River Delta. The demonstration projects applying for acceptance have completed an investment of over 20 billion yuan, involving the construction of 56 comprehensive freight hubs and 128 connection facilities (e.g., railway dedicated lines, container yards), driving more than 1,000 upstream and downstream enterprises to participate in multimodal transport-related work, including logistics enterprises, port operators, and manufacturing enterprises. For example, the Lianyungang Multimodal Transport Demonstration Project has built a "port-rail-yard" integrated hub, reducing the transfer time between sea and rail by 30% [5]. However, the concentration of these advanced hubs in eastern provinces highlights a potential challenge of regional disparity, which will be explored in the following section.

2.2 Market Scale

The market scale of multimodal transport in China has expanded rapidly, demonstrating its growing economic importance. In terms of market scale, multimodal transport has shown a steady growth trend. Container Multimodal transport volume has increased continuously, reaching 350 million TEUs in 2023, a year-on-year increase of 12%. Key channels such as the Western Land-Sea New Corridor and the China-Laos Railway have broken through critical freight volume nodes: the Western Land-Sea New Corridor achieved a freight volume of 80 million tons in 2023, a year-on-year increase of 25%; the China-Laos Railway, which has been in operation for three years, has completed a cumulative freight volume of over 10 million tons, covering more than 10 countries and regions in Southeast Asia. In the technical field, the collaborative optimization model developed by He Shiwei's team of Beijing Jiaotong University has achieved remarkable results in practical application, reducing total operating costs by 5%-7.5% for the Tianjin Port-Lanzhou dry port route [2]. Despite this growth, the market remains fragmented, with regional enterprises dominating, raising questions about operational efficiency and standardization on a national scale.

2.3 Low-carbon Development

Low-carbon initiatives are gaining traction, aligning multimodal transport with national sustainability goals.
In terms of low-carbon development, green transport modes have been gradually promoted, achieving significant environmental and economic benefits. The Guiyang-Shenyang multimodal transport route, which adopts a "railway-waterway" combination mode, has reduced CO_2 emissions by 41% and transportation costs by 28% compared with the traditional "road-only" mode. Anhui Province has actively promoted the use of new energy container trucks in port collection and distribution, and the carbon emissions of port collection and distribution have decreased by 29%. By 2023, more than 30 provinces will have launched low-carbon multimodal transport pilot projects, covering 120 key routes and reducing cumulative carbon emissions by 5 million tons. While promising, these pilot projects are often reliant on policy support and advanced infrastructure, posing challenges for widespread adoption, especially among SMEs and in less developed regions.

3. Diagnostic Analysis of Core Dilemmas in China's Multimodal Transport Supply Chain

Despite phased progress in infrastructure and market expansion, in-depth analysis shows China's multimodal transport supply chain faces three interrelated core dilemmas, severely restricting its high-quality development. Moreover, these dilemmas are not isolated; they form a vicious cycle. The market and legal fragmentation) fundamentally underpin the information silos and standard

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conflicts, which in turn exacerbate regional imbalances and hinder the adoption of integrated low-carbon technologies.

3.1 Market Operation, Legal Environment and Operating Cost Dilemmas

Regional enterprises dominate the multimodal transport market, lacking end-to-end capabilities and product stability. For instance, the China-Europe Railway Express has a 70% on-time rate, with train schedule fluctuations spanning 3–5 days, disrupting enterprises' cargo delivery plans. Most regional enterprises rely heavily on government subsidies: 80% derive 20%–40% of their income from subsidies, while some western railway firms depend on over 50%, threatening sustainability if subsidies are reduced. This subsidy dependence creates a market distortion, where competitiveness is artificially maintained rather than driven by operational efficiency, thus perpetuating the fragmentation of the market.

SMEs (90% of market entities) lack large-scale resource integration. The "bulk-to-container" penetration rate is 15% in China, far below 75% (U.S.) and 68% (EU), due to high containerization costs (2,000–3,000 yuan per container) and poor scale effects. Additionally, railway-shipping data exchange costs 5–8 yuan/TEU (raising enterprise costs by 10%–15%), and sea-rail node interoperability is <30%. Enterprises cannot obtain real-time cargo status (e.g., arrival time, transfer progress) and must rely on manual confirmation, increasing workload and undermining efficiency.

Legally, international transport faces complex customs clearance: 8–10 procedures for multi-customs declaration, 48-hour cross-regional verification, and coordination costs taking 15%–20% of total transport costs [3]. A pressing issue is the Maritime Code-Contract Law "dual division", triggering legal conflicts. In 2023, a Shanghai-Hamburg "sea-rail" cargo damage case led to a 10-month dispute over legal application, causing 200 million yuan in losses. The Shanghai International Economic and Trade Court found that 60% of international disputes stem from this.

Operationally, poor cross-mode scheduling limits capacity utilization to 65% (85% in developed countries). Major ports have a 35% empty container return rate, with cross-yard costs taking 20% of container operation costs. Imperfect infrastructure forces high-cost road transport—bulk goods road costs are 5x that of multimodal transport. For example, Shanxi-Guangzhou coal transport costs 800 yuan/ton (road) vs. 160 yuan/ton ("railway-waterway"), but 60% of Shanxi coal mines lack dedicated railways. This operational and legal disarray naturally leads to and magnifies the challenges of information sharing and standard unification, which will be discussed next.

3.2 Information Sharing and Standardization Difficulties

Multimodal transport information platforms have limited coverage, with "information silos" across regions and modes. China has built 18 provincial platforms, but they use incompatible standards: Jiangsu's GB/T 1836-2022 vs. Guangdong's ISO 6346-2020 [1]. Cargo data from Jiangsu cannot be directly recognized in Guangdong, requiring manual re-entry and adding inefficiencies to cross-regional logistics.

Even in the same region, transport modes use independent systems (railway's "National Railway Freight Management System", road's "Road Transport Information Platform", waterway's "Port EDI System") without data interfaces. Enterprises input identical information 2–3 times, raising error rates by 15% and labor costs by 20%. Data standards conflict: railways define "cargo weight" as gross weight, roads as net weight; waterways calculate "transport time" as departure time, air as arrival time. A Shanghai firm received "5 tons" (gross) from railways, arranged a 5-ton truck (net), causing overloading and a 3-day delay.

Though the "single bill system" has national standards, cross-regional recognition is incomplete, and formats conflict across sea, land, and air. Shanghai requires "container inspection records", Guangzhou "cargo insurance info", Shenzhen "customs declaration numbers"—a Shanghai waybill is invalid in Guangzhou, raising transaction costs by 10% [1]. Even with the Container Multimodal Transport Waybill standard, cross-mode interfaces and security specs are missing. Interface transformation costs 100,000–500,000 yuan per enterprise, which is unaffordable for 70% of SMEs. Full logistics tracking coverage is only 60%. The pervasive information barriers and incompatible standards not only inflate costs but also critically undermine the coordinated, nationwide deployment of resources and technologies, which is the focus of the following section on regional and low-carbon challenges.

3.3 Regional Development Imbalance and Low-Carbon Technology Barriers

Regional imbalance bottlenecks national logistics coordination. Shen & Zong found multimodal scores: East China 2.8/5, Central 2.1/5, West 1.2/5 [4]. Gaps exist in: infrastructure density (East: 4.2 hubs/100,000 km² vs. West: 0.9); market scale (East: 65% of national container volume vs. West: 15%); technical application (70% of intelligent projects in Yangtze/Pearl River Deltas vs. <10% in southwest).

Three factors cause this gap: economic demand (Yangtze River Delta: 500,000+ manufacturers, 100M-ton annual demand; northwest: 80,000+ manufacturers, 15M-ton); infrastructure investment (East: 120B yuan vs. West: 20B yuan, 2020–2023); policy support (East: 20% land fee cut +15% corporate tax reduction; West: only direct subsidies).

Low-carbon tech faces obstacles. “Railway-waterway” promotion is limited by infrastructure: southwest railway coverage 60%, upper Yellow River navigable mileage 500 km (unable to carry 5,000-ton ships). This is not merely an infrastructure issue but a manifestation of the ‘first-mile’ connectivity problem rooted in the market and investment imbalances discussed in section 3.1.

A Sichuan logistics enterprise had to switch to road transport (3x railway emissions) for agricultural products, as the nearest railway station was 80 km away. Blockchain/digital twin tech works in carbon accounting, but no “regulatory sandbox” causes coordination issues—a Shandong firm’s 5M-yuan blockchain investment failed, as carbon credits were unrecognized [8].

SMEs lack green motivation due to high costs: fully electric port equipment costs over 100M yuan (8–10 year payback), new energy trucks cost 400,000 yuan (2x fuel trucks). With average annual profits <5M yuan, 85% cannot afford this—only 15% of SMEs use new energy equipment vs. 85% of large firms [9]. Academic models (Changsha University of Science and Technology’s five-element model, Chongqing Jiaotong University’s low-carbon path model) are hard to promote due to data access issues and low SME acceptance [10].

4. Proposed Optimization Strategies and Implementation Pathways

Aiming at the root causes of identified problems (insufficient Infrastructure Interconnectivity, inconsistent standards, and technology-practice disconnection), this study proposes targeted suggestions by referring to international experience and China’s national conditions.

4.1 Building an Integrated Infrastructure and Standardization Framework

To directly address the information silos and standard conflicts, this study first suggests accelerating cross-regional mutual recognition of the “single bill system” and unifying standards. This study suggests establishing a national multimodal transport standardization committee, jointly formed by the Ministry of Transport, industry associations, enterprises, and academia. The committee shall formulate three unified standards by late 2025: (1) Data standards: define 120+ core indicators (e.g., “cargo weight” as gross weight, “transport time” as departure time) and adopt ISO 6346-2020 coding; (2) Waybill standards: unify Container Multimodal Transport Waybill format (8 mandatory fields like cargo info, 5 optional fields) for sea-land-air compatibility; (3) Interface standards: set cross-mode interface specs (supporting JSON/XML) and SM4 encryption-based security standards [11]. A national waybill mutual recognition platform shall be built for “one submission, nationwide recognition”—enterprises submit data once, and it is auto-recognized by customs and transport firms [3]. Drawing on the EU’s “Single Administrative Document (SAD)”, a “mandatory + incentive” mechanism is adopted: standards are mandatory for demonstration projects; compliant enterprises get 10% higher subsidies and priority in project approval.

Building upon standardized data exchange to further overcome the real-time tracking limitations and trust deficits, a national blockchain-based information sharing platform should be established. The Ministry of Transport shall invest 5 billion yuan in an alliance chain platform, with nodes covering transport enterprises, customs, and regulators [11]. It integrates four functions: (1) Data exchange center: offering unified interfaces for 200+ real-time logistics data fields (e.g., transport capacity, cargo status); (2) Full-process tracking center: connecting IoT devices (GPS, sensors) to reach 90% coverage by 2026; (3) Security authentication center: using blockchain for data immutability; (4) Credit evaluation center: recording enterprise service quality to support SME financing. The platform charges 0.5 yuan/TEU (far below the current 5–8 yuan) for sustainability and opens anonymized data to academia.

Third, strengthen infrastructure and optimize routes. Allocate 80 billion yuan (2024–2026) to build 20 central-western freight hubs (e.g., Lanzhou, Chengdu), each with 3+ dedicated railways, 2 container yards, and 1 automated transfer facility (transfer time <12h). Expand “railway + waterway” routes (Lanzhou-Lianyungang, Chongqing-Guangzhou) to link western resources with eastern ports [12]. Promote dedicated railways for ports/industrial parks—by 2026, all 10M-ton ports and 5M-ton industrial parks shall connect to railways. For example, a 20km Shanxi coal mine railway linking Daqin Railway reduces road dependence by 40%. The PPP model is adopted to attract social capital, with the government bearing 30% of investment and policy risks.

4.2 Strengthening the Policy, Legal, and Market Ecosystem

To resolve the legal voids and conflicts, particularly the ‘dual division’ of the Maritime Code and Contract Law, it is imperative to advance the legislation of a dedicated Multimodal Transport Law. Include it in the 2025 national legislative plan to clarify: (1) Unified liability system: operators bear joint liability for the whole process, with 100 yuan/kg compensation for damaged cargo; (2) Legal coordination: the law prevails in cross-mode transport to resolve Maritime Code-Contract Law conflicts; (3) Simplified customs clearance: “one-stop” system for “single declaration, multiple clearances” (verification time <6h). Formulate implementation rules within 6 months and

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establish a national arbitration center to shorten dispute handling to <3 Months.

Second, improve market mechanisms and support SMEs. Support large enterprises (e.g., China Railway Express, COSCO Shipping) in cross-regional mergers, with a 5% government subsidy for merger funds. Cultivate 3–5 national leaders (40% market share) by 2027. Provide targeted SME subsidies: 50% of container costs for "bulk-to-container" conversion, 30% of interface transformation costs for platform access, 20% of new energy equipment costs. These targeted subsidies are designed to lower the upfront cost barrier that currently discourages SME participation, thereby stimulating market vitality and inclusivity.

Launch "multimodal transport credit loans" (1% lower interest) with banks; negotiate to cut railway-shipping data fees to <1 yuan/TEU (government subsidizes the rest). Conduct quarterly fair competition inspections to crack down on price-fixing [9].

Third, a low-carbon technology promotion mechanism should be established. Incorporate low-carbon multimodal transport into the national "dual carbon" plan, targeting 30% railway-waterway routes by 2027 [12]. Set up a 10 billion yuan special fund: 20% subsidy for new energy equipment, 10 yuan/ton for carbon reductions (10% higher for SMEs). Launch a "regulatory sandbox" pilot in the Yangtze/Pearl River Deltas to test blockchain/digital twins, and formulate standards within 1 year. Strengthen university-enterprise cooperation: encourage universities (e.g., Beijing Jiaotong University) to set up "multimodal transport low-carbon technology" majors; build SME training bases to train 10,000 talents by 2026.

5. Conclusion

5.1 Concluding Remarks and Theoretical Contribution

This study systematically analyzes China's multimodal transport supply chain and obtains key findings: First, it has achieved phased progress—28-province demonstration routes form a basic network, container volume grows steadily, optimization models cut costs by 5%-7.5%, and low-carbon routes reduce emissions by up to 41%—providing strong support for dual circulation and the "Belt and Road Initiative". Second, three interrelated dilemmas hinder development: fragmented markets (top 10 enterprises hold only 25% of shares), legal conflicts (60% of international disputes from legal division), and high road transport costs (5x that of multimodal); widespread information silos and inconsistent standards limit full-process tracking to 60%; severe regional imbalance (eastern scores 2.3x western) and high transformation costs block low-carbon technology adoption (SMEs' new energy rate is 15%). These stem from poor Infrastructure Interconnectivity, standard conflicts, and technology-practice disconnection. Third, suggestions focus on two dimensions: improving infrastructure/standards (unifying data/waybills, building a blockchain platform) and optimizing policies/laws (promoting legislation, supporting SMEs).

5.2 Practical and Policy Implications

Practically, it offers targeted references: governments can use legislative and infrastructure plans for precise policy-making to narrow regional gaps; logistics enterprises, especially SMEs, can cut costs by 15%-20% via platform access and subsidies; industry associations can formulate norms to integrate fragmented markets. Socially, it helps lower logistics costs' GDP ratio, contributing to affordable consumer goods; low-carbon mode promotion supports the "dual carbon" goal with 10 million tons of annual emission cuts; optimized legal/customs systems shorten cross-border time by 30%, boosting international competitiveness for national strategies.

5.3 Limitations and Future Research

This study has limitations: it relies mainly on secondary data, which may have timeliness differences, and lacks primary data from enterprise interviews to grasp SMEs' specific subsidy/technology needs. Its national scope neglects regional characteristics, such as western resource-based regions' unique demands. Future research will survey 200-300 enterprises (covering east/west, large/SMEs) to verify suggestions, take western China as a case to design targeted plans, and explore AI's application in intelligent low-carbon path optimization for specific routes like Chongqing-Guangzhou.

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