



## ENHANCING OPERATIONAL EFFICIENCY OF CHINA-EUROPE FREIGHT TRAIN SERVICE: A CASE STUDY OF XI'AN TERMINAL

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### Abstract

China-Europe Freight Train (CEFT) has become a vital component of Eurasian logistics, yet its operational efficiency faces significant challenges. This study identifies key bottlenecks and strategic improvement areas after reviewing CEFT's historical development and current status. Special attention is given to Xi'an terminal, a critical hub for CEFT operations. Using a hybrid approach that combines qualitative assessment with quantitative analysis, the research evaluates influential factors, operational processes, and external disruptions. Findings reveal that while events such as the COVID-19 pandemic and the Suez Canal blockage accelerated CEFT growth, geopolitical tensions and sanctions linked to the Russo-Ukrainian War have constrained its development. As CEFT enters its maturity phase, the focus shifts from rapid expansion to quality-driven strategies emphasizing efficiency and competitiveness. To support this transition, five key performance indicators (KPIs) are proposed for Xi'an terminal to monitor and optimize performance. These KPIs aim to reduce transit times, lower costs, and enhance reliability, enabling stakeholders to streamline processes and strengthen China-Europe trade. This research contributes actionable insights for logistics operators, policymakers, and supply chain managers seeking to improve CEFT's resilience and competitiveness in a dynamic global environment.

*Keywords: China-Europe freight train, belt and road Initiative, Xi'an terminal, freight transportation, China-Europe trade, cross-border rail transport*

### 1 Introduction

The China–Europe freight train (CEFT), operated on scheduled, predefined Eurasian corridors, has emerged as a viable alternative to maritime and air freight. Its value proposition hinges on balancing lead time, reliability, and inventory exposure rather than optimizing a single dimension. Rapid network growth increased operational complexity: heterogeneous regulations, infrastructure and terminal capabilities, and multi-actor handovers affect capacity utilization and schedule stability. Meanwhile, decision-makers demand comparable evidence of efficiency and reliability, yet transparent, operational data are scarce and definitions of punctuality, transit time, or asset utilization vary widely. This paper responds by shifting from descriptive narratives to an evidence-based operational perspective. It develops a small, standardized KPI set aligned with shippers', operators', and terminal managers' decisions, and links indicators to concrete levers. The Belt and Road Initiative (BRI) is acknowledged as context but not the analytical focus.

## 2 Current state of research on the China–Europe freight train

Since its introduction, the BRI has attracted the attention of numerous scholars in China and abroad [1]. Likewise, the China-Europe freight train (CEFT) launched and operated by several Chinese cities [2] has drawn a great deal of scholarly attention for in-depth analysis. Firstly, the researchers collected data to examine the overall opening status of the CEFT. They sorted out and summarized several major development problems of CEFT, and concluded that the train has many problems, such as an unbalanced volume of outbound and return trips [3], insufficient volume of eastbound trains [4], transit time limited by bad weather [5], natural disasters [6] and technology issues [7], low efficiency of cargo clearance [8], and unorganized competition among major platforms [9]. Researchers have responded to these developments by proposing corresponding train operation improvements [10]. In addition, some researchers analysed the current development status [11] and early problems of CEFT from the perspective of one-belt-one-road [12] and put forward suggestions for modification. This will help improve the development of CEFT and promote the transfer and upgrading of Chinese industries to the central and western inland regions [13]. The experts analysed and affirmed the CEFT in terms of both geographic distribution [14] and domestic [15] and international strategic position [16] respectively. They repeatedly identified the development potential of CEFT [17] and analysed and predicted the development affecting CEFT from different perspectives, such as technology [18], cargo sources [19], and government subsidies [20]. Simultaneously, there are numerous studies analysing the development of CEFT from the management level [21], equipment level [22], cargo source support level and encouraging market level [23]. CEFT, as a new mode of transportation between China and Europe, has steadily entered the stage of rapid development after the initial introduction stage [24]. In summary, current research on CEFT focuses on macro effects or modelling approaches. Operational KPI-based performance monitoring at the terminal level has not yet been extensively researched.

## 3 Case study Xi'an

Xi'an is an ideal KPI test case because it occupies a strategically central position in China and serves as a major hub of the China–Europe freight train network. Its high-frequency, stable rail operations and advanced terminal infrastructure make it well-suited for evaluating performance, efficiency, and reliability indicators. The city's extensive multimodal connections to major Chinese economic regions ensure representative and scalable KPI measurements. Additionally, Xi'an's rapidly growing international trade and industrial clustering provide rich data for economic and logistics KPIs. Finally, innovative policies such as land-based tax rebates and integrated e-commerce logistics make Xi'an a forward-looking benchmark for testing modern supply chain KPIs. The study analyses data on the operational development of CEFT from Xi'an International Railway Station between 2013 and 2022. The data were collected from the official website of CEFT Transportation official statistics published on the websites of relevant organizations and departments and press reports [25-27].

### 3.1 Operational efficiency and key performance indicators

As it enters a mature stage of development, the measurement and monitoring of CEFT operational efficiency becomes an important tool to enhance its services. Following da Silva et al. [28] and standard terminal KPI frameworks, the authors reduced the longlist of more than 20 indicators to a shortlist of 5 KPIs through relevance, measurability and operator controllability. After years of cultivating the market through subsidy policies, the Xi'an terminal has recruited a relatively stable source of goods. Subsequently, as the subsidy is phased off, the emphasis naturally shifts towards reducing logistics costs by enhancing the efficiency of train operations.

To quantify the operational efficiency of CEFT Xi'an trains, a performance measurement system is required to be established. Efficiency implies the act of maximizing the results obtained from a given set of resources (technical efficiency) or achieving an ideal combination of resources to maximize output (allocative efficiency).

**Table 1** Selected KPIs for evaluating the operational efficiency of CEFT Xi'an

Strategic objective	Indicator	Formula	Frequency
Maximize the availability and guarantee the reliability of assets to achieve the excellence of maintenance management	Wagon availability [%]	$\sum_{l=1}^N \left[ \frac{\text{Wagon.havailable}}{\text{Totalwagons.h}} \right] \cdot 100 / N$ N = Days accumulated on month	Monthly/daily
Guarantee production excellence on Communication	Respond efficiency [%]	$\sum_{l=1}^N \left[ \frac{\text{Totalcommunicatingtime}}{\text{Expectedcommunicatingtime}} \right] \cdot \frac{100}{N}$ N = Days accumulated on month	Monthly/daily
Guarantee production excellence on transportation	Transportation production efficiency [%]	$\sum_{l=1}^N \left[ \frac{\text{Trainsperformed}}{\text{Trainsplanned}} \right] \cdot 100 / N$ N = Days accumulated on month	Monthly/daily
Guarantee and improve trains circulation to achieve excellence on transportation operations	Train cycle efficiency [%]	$\sum_{l=1}^N \left[ \frac{\text{Eastboundtrains}}{\text{Westboundtrains}} \right] \cdot 100 / N$ N = Days accumulated on month	Monthly/daily
	Accident Index	$\frac{\text{AccidentsOcuired}}{\text{Totalnumberoftrainsonth}}$	Monthly

When contemplating efficiency, individuals tend to focus on a solitary dimension, a singular numerical value, or a percentage. However, railway freight is not characterized by simplicity. The rail system consists of two types of resources: static resources, such as tracks, terminals, and signalling or communication systems, and dynamic resources, such as rolling stock. Efficiently managing these resources is crucial for the operating efficiency of the system. The primary purpose of CEFT operators is to efficiently coordinate and utilize all available rail resources and assets. To effectively administer the CEFT sub-systems, a series of Key Performance Indicators (KPIs) would be utilized to evaluate the operational performance of CEFT Xi'an and seek operational improvements. Normally, the operational processes indicators may include the productivity of locomotives, wagons and rail, the terminals utilization rate, the availability of terminals, locomotives, wagons, and rail, the timeline accomplishment of recovery rolling materials project and construction and recovery of rail projects, the reliability of locomotives, the CEFT transit time, the wagon cycle time, the utilization of traction capacity and wagon capacity, the accident index, the efficiency of loading and unloading, the permanence time of terminal wagons, the trucks waiting time, the production of transportation efficiency, the energy efficiency, and the accuracy of production monthly planning (cf. da Silva et al. 2020:123). However, the optimizing number of KPIs in practice is expected between three to six. This requires operators to select the three to six most representative KPIs from a pool of KPIs to utilize as actual performance measurement parameters (table 1).

### **3.1.1 KPI 1: Wagon availability**

The scarcity of wagons is a frequent challenge in the regular operation of CEFT. Therefore, the availability of wagons at the terminal has been selected as one of the indicators to assess the efficiency of terminal operations. Wagon availability measures the share of time a railcar fleet is operational rather than in maintenance or idle (table 1). At the maintenance level of operation, the wagon availability of Xi'an International Port Station in 2022 reached 46.39% which is approximately equal to half of the wagon capacity of the station.

### **3.1.2 KPI 2: Respond efficiency**

Subsequently, due to the involvement of multiple stakeholders in CEFT activities, the daily operating concerns of the terminal would heavily rely on the transmission and sharing of information. Thus, respond efficiency has been selected as a metric to gauge the effectiveness of CEFT activities. Respond Efficiency measures how well and how quickly the parties involved (e.g., railways, terminals, freight forwarders, etc.) communicate with each other and how close the actual communication speed is to the planned target time (table 1). In terms of communication performance, although the response rate of CEFT Xi'an achieved 100% in 2022, the respond efficiency was around 75.83% according to the estimated requirement of responding to any stakeholders within 2 hours. This indicates that for each communication between CEFT operators and other stakeholders, there is about 24.17% waiting time.

### **3.1.3 KPI 3: Transportation production efficiency**

Transportation production efficiency represents the portion of shipped trains in planned trains. This percentage demonstrates the ability of Xi'an terminal to adhere to the planned schedule for delivering the 55 required shipment slots. It also reflects its ability to collect cargo (table 1). As for the transportation production efficiency of Xi'an freight trains between China and Europe, the efficiency rate hit 100% in the first two quarters of 2023, compared to 98.4% in 2022. This high efficiency benefited from the advanced booking policy and slot overbooking mechanism.

### **3.1.4 KPI 4: Train cycle efficiency**

The train cycle efficiency has been characterized as the ratio of the number of eastbound trains to the number of westbound trains. An optimal scenario would entail achieving a ratio of 100%. The greater the deviation of this metric from 100%, the more imbalanced the east-west trains are, indicating the performance of the CEFT in terms of the reciprocal arrangement of trains (table 1). The train cycle efficiency of Xi'an freight trains decreased from 181.94% in 2018 to 101.62% in 2022, which illustrates a much more balanced container moving between China and Europe based on historical data from the Ministry of Commerce of the People's Republic of China.

### **3.1.5 KPI 5: Accident index**

The monthly accident index has been chosen as the primary statistic for terminal operations to measure the accident rate of CEFT. While train freight accidents are exceedingly uncommon, it is imperative to continuously check transportation safety due to its paramount significance (table 1). The traffic accident rate of the Xi'an freight train has been maintained at 0 since its operation in 2013, with no major traffic accidents. And this is the reason why train freight is considered a safer mode of transportation.

### 3.2 Challenges and bottlenecks

The operational KPIs indicate that the operational performance of the Xi'an terminal still needs enhancement. The operational inefficiency of Xi'an freight trains is identified with the assistance of the Ishikawa diagram (figure 1).

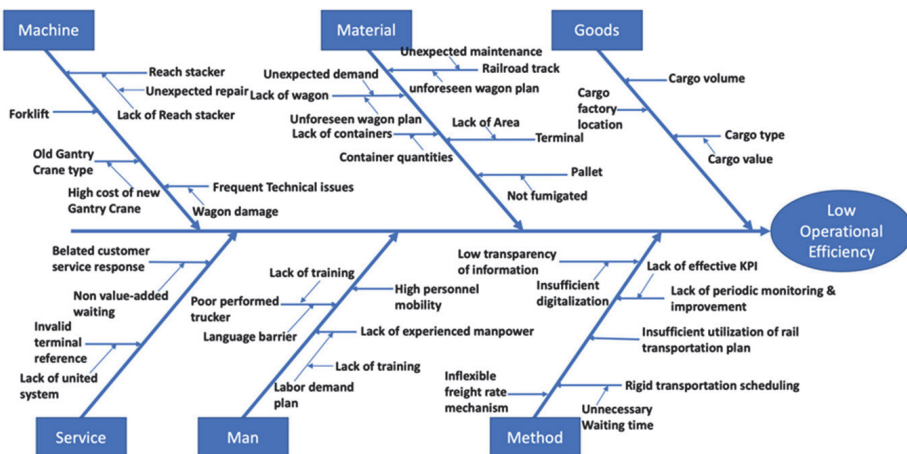


Figure 1 Challenges and bottlenecks identification of CEFT Xi'an freight trains

The challenges and bottlenecks identified include a scarcity of cargo sources, insufficient transportation equipment, low-performing terminal machinery, subpar service quality, a dearth of skilled staff, and an inadequate regulatory framework.

#### 3.2.1 Cargo structure and market dynamics affecting transportation production efficiency (KPI 3)

The efficient operation of static resources is required to keep up with fluctuations in demand, which indicates changes in the volume, type, value, and distribution of cargo. As freight subsidies fade, the affordability of low-value cargoes decreases. This might potentially alleviate congestion at the ports, but it may also lead to shortages of freight trains. It will further restructure the cargo structure of Xi'an freight trains, which would require the operators to retarget and market space to their customer base. Moreover, in terms of the hub-driven effect of Xi'an, the distribution of local cargo is about 30%, which illustrates an insufficient integration between Xi'an freight train and local enterprises.

#### 3.2.2 Infrastructure and terminal capacity affecting wagon availability (KPI 1) and train cycle efficiency (KPI 4)

On the other hand, the infrastructure for Xi'an freight trains is expected to be optimized. The infrastructure of Xi'an International Port Station is still incomplete, with the construction of its comprehensive railroad logistics center progressing slowly. Additionally, the small size of the customs supervision operating area and the container yard also have a negative impact on the operational efficiency of Xi'an freight trains. And the variable train cycle efficiency reflects the imbalanced movement of boarding wagons and containers. This leads to elevated freight rates, challenging turnover of transportation wagons, and diminished overall transportation efficiency, as well as congestion at the ports.

Furthermore, the inadequate response efficiency exposes that the informatization level of the Xi'an railway freight platform still requires enhancement. Although the Xi'an railway freight platform provides an online single-window booking platform and an integrated service platform for shippers to make online bookings and search for the updated status of their shipments, its customer service is currently limited to email communication. This results in non-value-added waiting time on communication, which decreases the effectiveness and satisfaction of customer service.

### **3.2.3 Information systems and communication efficiency affecting wagon response cycle efficiency (KPI 2)**

Insufficient digitalization of information exchange continues to hinder the operational efficiency of communication, data sharing, and data transfer among all stakeholders. In addition, the shortage of skilled labour in this domain further exacerbates inefficiencies in day-to-day communication processes (see next chapter). At Xi'an Terminal, the current challenges include inadequate digitalization within terminal administration, a rigid pricing mechanism, limited monitoring and upgrading of cyclical performance, insufficient execution of operational plans, and inflexible shipment planning. The lack of a standardized terminal information system results in uneven distribution of information across departments, leading to reduced transparency and overall diminished clarity in operational processes.

### **3.2.4 Human resources and skill shortages affecting transportation production efficiency (KPI 3)**

Enhancing efficiency is a significant focus at the terminal, with a particular emphasis on acquiring top-notch human resources. Amidst the economic recession that ensued the epidemic, there was an abundance of available workers, but a scarcity of skilled professionals. This phenomenon can be attributed partially to the significant mobility of professionals and partially to the absence of specialized training. One often neglected human resource is the truck driver. Currently, most shippers choose to utilize third-party trucking services, rendering it unfeasible to exercise control over the quality of service provided by truckers. Due to the presence of various local languages in various regions, drivers hailing from different provinces could encounter difficulties in properly communicating with the terminal. The subsequent array of supplementary expenses poses a significant source of frustration for last-mile transportation providers.

### **3.2.5 External geopolitical and macroeconomic factors affecting train cycle efficiency (KPI 4)**

The current CEFT pricing mechanism is particularly inflexible in an environment full of various external factors such as the pandemic, the Russo-Ukrainian War, and the potentially Israeli-Palestinian Conflict. Furthermore, the terminal suffers from a deficiency in monitoring and enhancing efficiency, maybe resulting from the absence of KPIs. In addition, the implementation of the CEFT plan is incomplete, and its scheduling is expected to be enhanced to minimize non-essential waiting time.

## **3.3 Strategies to improve operational efficiency**

The following strategies, based on challenges and bottleneck, outline how the operational efficiency of CEFT operations at the Xi'an terminal can be specifically improved.

### **3.3.1 Cargo strategy and market repositioning**

To enhance the operational efficiency of the Xi'an platform within the China-Europe freight transport network, a primary requirement is the strategic restructuring of the cargo composition. As governmental subsidies progressively diminish and freight tariffs rise, the origins and structural characteristics of cargo flows are undergoing notable transformation, thereby necessitating a systematic re-profiling of customer segments. Operators should intensify their efforts to attract local and high-value cargo, as such goods accelerate consolidation processes, reduce the complexity of information processing, and contribute to higher terminal productivity.

### **3.3.2 Infrastructure development**

Concurrently, the application of differentiated and data-driven pricing mechanisms enables a more precise steering of demand and facilitates adaptation to short-term market volatility as well as long-term structural shifts. Political actors play a crucial enabling role in this context by designing flexible, market-compatible incentive frameworks which support the establishment of stable, long-term cargo sources and reinforce regional competitiveness. In parallel, the targeted expansion and modernization of infrastructure represent a second pivotal dimension for improving system performance. Given that the capacity of China–Europe freight trains is largely contingent upon the reception and processing capabilities of ports and terminals, substantial investments in railway ports, customs supervision zones, container yards, and inspection technologies are indispensable. Additionally, the development of multimodal transport corridors including dedicated air-rail, road-rail, and sea-rail connections - enhances spatial connectivity and strengthens operational resilience. In light of ongoing geopolitical uncertainties, particularly those arising from the Russia–Ukraine conflict, the diversification of transport routes becomes increasingly essential, as alternative corridors may mitigate customs bottlenecks, reduce transit times, and stabilize overall network performance. The implementation of these infrastructure initiatives depends on coordinated action between platform operators, local governments, and financial institutions, for instance through future-revenue-based financing structures or policy frameworks that enable more efficient cross-border corridor development and customs harmonization.

### **3.3.3 Digital transformation**

A third essential component concerns the acceleration of the platform's digital transformation. The creation of a unified single-window information system - integrating the data flows of customs authorities, railway bureaus, operators, and freight forwarders - has the potential to eliminate redundant communication steps, reduce non-value-adding waiting times, and enhance transparency across the logistics chain. The deployment of advanced digital technologies, such as big data analytics, cloud computing, satellitebased positioning, and artificial intelligence, can substantially improve realtime capacity allocation, optimize scheduling, and support data-driven decision-making.

### **3.3.4 Workforce and capability development**

However, the realization of technological advancements requires comprehensive workforce training as well as the recruitment of specialized professionals capable of designing, implementing, and maintaining digital infrastructures. From a policy perspective, regulatory frameworks that establish clear standards for data interoperability, cybersecurity, and digital customs procedures are indispensable for ensuring the reliability and scalability of such systems.

Furthermore, the introduction of dynamic, data-supported tariff mechanisms enables faster rate adjustments in response to market conditions, thereby increasing the attractiveness of rail freight transportation. This includes targeted training programs that equip employees with the digital, analytical, and operational skills required to manage increasingly automated and data-driven logistics environments.

### **3.3.5 Service differentiation and network integration**

Finally, strengthening the competitiveness of the Xi'an platform requires a shift from price-based competition towards a model centered on service differentiation and the provision of high-value, integrated solutions. This includes the formation of strategic alliances with financial institutions, e-commerce firms, insurance providers, warehousing operators, and logistics service companies to establish comprehensive cross-border trade services encompassing payment systems, credit guarantees, overseas warehousing, and integrated international logistics. Further development of public overseas warehouses, cross-border e-commerce logistics, and bonded exhibition or distribution centers in key CEFT hubs may significantly expand the platform's service portfolio and reinforce its position within the broader Asia–Europe trade ecosystem. Realizing these advancements requires supportive regulatory conditions in the fields of customs processing, bondedzone administration, and international digitaltrade standards, ensuring legal certainty and facilitating seamless multimodal operations across borders.

## **4 Conclusion**

The case of Xi'an demonstrates that the operational efficiency of the China–Europe Freight Train (CEFT) cannot be evaluated adequately through macro-level indicators alone. By developing and applying a concise, operator-oriented KPI system to the case of Xi'an, the article provides a structured approach for translating complex rail-based logistics processes into measurable performance dimensions. The results show that while Xi'an has achieved strong production performance and high safety standards, persistent inefficiencies. Bottlenecks are closely linked to structural market dynamics, infrastructure limitations, insufficient digital integration, and shortages of specialized workforce capabilities.

The strategic analysis highlights that improving CEFT performance requires a coordinated, multi-dimensional approach. Strengthening local and high-value cargo acquisition, expanding and modernizing terminal and customs infrastructure, accelerating digitalization through a unified single-window system, and investing in workforce development are fundamental levers for increasing efficiency and reducing non-value-adding time. Moreover, the shift from price-based to service-oriented competition underscores the need for deeper network integration, including multimodal connectivity and partnerships with financial, e-commerce, and logistics service providers. Such measures not only enhance operational performance but also improve the resilience and long-term competitiveness of CEFT routes in a volatile geopolitical environment.

The proposed KPI framework offers practical value for terminal operators, policymakers, and logistics stakeholders by supporting more transparent monitoring, benchmarking, and decision-making. At the same time, the study is subject to limitations. As a single-case analysis, its findings cannot be generalized without further comparative research across additional CEFT hubs, and data constraints restrict the depth of some indicators. Future research could extend the KPI framework through longitudinal studies, cross-terminal benchmarking, or simulation-based analyses to better capture dynamic interactions between operational and external factors.

Despite these limitations, the study provides a robust foundation for evidence-based performance management in Eurasian rail logistics and points toward concrete pathways for enhancing the operational maturity of CEFT terminals. This research is, however, subject to several limitations. The analysis draws on a single case, which restricts the generalizability of the conclusions. Some resilience factors are difficult to quantify and thus only partially reflected in the KPI system. Data availability imposes boundaries on the depth of empirical validation, and the dynamic interactions of external influences can only be captured to a limited extent. Furthermore, the study focuses primarily on past performance and does not forecast future developments.

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