

Chapter 2

A Heavy-Haul Path with Chinese Characteristics

When we hear “heavy-haul,” the first thing that comes to mind is its ability to transport significantly more freight than conventional railcars. Truly, heavy-haul railway transport features a single train carrying much more freight than a conventional train, with an increase of transport volume and a decrease of transportation costs. But how more could its freight be? According to the advanced international standards in the 1980s, heavy-haul transport typically refers to trains with a load capacity of more than 5,000 tonnes, suitable for the bulk, long-distance movement of cargo.

Heavy-haul railways are also defined by their length, directness, and exclusiveness. Length refers to a minimum haul distance of 150 km. Directness means cargo being transported primarily through direct routes, with no en-route reclassification (switching) or full-car loading/unloading operations. Exclusiveness indicates that the trains carry mainly a single type of bulk commodity, such as coal or iron ore. In other words, heavy-haul transport uses railcars with large carrying capacities, long and heavy train formations, and double or multiple high-powered diesel or electric locomotives, to move bulk freight.

As industrial and mining enterprises experienced a surge in cargo volumes, traditional rail transport began to decline. To meet the demand for moving large quantities of goods, some countries addressed the need by increasing the length of train formations and boosting load capacities, and hence heavy-haul railways came into being. However, reaching a certain weight threshold alone does not fully define a heavy-haul railway—this is just one aspect of its standard, albeit the most fundamental and noticeable one. Operating heavy-haul trains also involves various technologies, including locomotives, rolling stock, braking systems, and communication.

Different countries face varying transport conditions, operational requirements, and existing rail infrastructure, resulting in diverse technical approaches to operating heavy-haul trains. Generally, there are two main methods: one is to increase axle load and thus lengthen train formation; the other is to boost overall train traction capacity. To address the challenges of transporting coal from Shanxi, China built a dedicated heavy-haul railway that emphasises the Chinese characteristic of “moving more, moving faster.” This approach neither simply replicated the transport models of the United States or the Soviet Union nor overlooked the reality that both passenger and freight rail services in China were severely strained.

Heavy-Haul Railway as a Large-Scale System

At the Third International Heavy-Haul Railways Conference in 1986, the heavy-haul railway was defined as follows: (1) a single line should have an annual capacity of no less than 20 million tonnes; (2) train traction weight should be at least 5,000 tonnes; and (3) axle load should be no less than 24 tonnes. A railway that meets at least two out of the three criteria could be termed as heavy-haul railway. In 1994, the heavy-haul train standard increased the axle load requirement from 24 tonnes to 25 tonnes, in addition to specifying that the minimum transport distance must not be less than 150 km.

In 2005, the International Heavy-Haul Association established clear standards for heavy-haul railways: (1) each train formation must have a traction load of at least 8,000 tonnes; (2) axle loads must not be less than 27 tonnes; and (3) railway line segment must be at least 150 km in length, with an annual freight volume of no less than 40 million tonnes. Satisfying any two of these three conditions qualifies a railway as a heavy-haul line.²⁹

Both carrying capacity and annual freight volume are visible figures, but they are invisibly supported by a large, integrated system. Most people are generally familiar with passenger railways, and from common knowledge, we understand that a railway does not simply involve the tracks laid on the ground and the trains running on them; it also includes stations along the line and the power supply facilities necessary for train operation. In technical terms, it comprises a vast system involving track, locomotive, rolling stock, electrical systems, and operational management. These are components within the railway system, whereas heavy-haul railways constitute a more complex system involving multiple sectors, within and outside the railway system.

The Da–Qin Railway is such a complex system. It includes not only the Da–Qin heavy-haul line itself. Within the system are also coal storage and loading facilities in northern Shanxi, the Phase III Coal Terminal at Qinhuangdao Port, and the Da–Qin Railway power supply project organized by the North China Power Grid. It integrates the coal industry, the power sector, and the local government, forming a cyclic coal transport system that features automatic coal loading, direct delivery, and continuous unloading. If any link in this chain falters, it can affect the operation of the entire system. Strictly speaking, the Da–Qin Heavy-Haul Railway described in this book is only one component of this large system, but it is by no means a simple one.

²⁹ Wen Bangyan and Wang You [文邦彦, 汪优], Opportunities and Challenges for the Development of Heavy-Haul Railways in China. *Technology and Market*, no. 7 (2014): 293–294+296. [我国重载铁路发展的机遇与挑战, 《技术与市场》7]

First, let's start from the word "heavy." Compared to conventional trains, heavy-haul trains have much greater total weight. While the weight of a conventional freight train is typically 3,000–4,000 tonnes, a heavy-haul train is two to three times, or even more, that weight. The requirements for rolling stock in heavy-haul transport differ from those of conventional trains, placing greater emphasis on maximising payload capacity while minimising the tare (unladen) weight of vehicles.

Increasing axle load is the primary approach used worldwide in developing heavy-haul trains, as axle load is a critical factor determining a train's loading capacity. Axle load is the maximum weight that an individual axle can carry when a vehicle is fully loaded. It is one of the key factors in assessing a track's load-bearing capacity. The axle load determines both the design standards for railway vehicles and their operational efficiency. The greater the axle load of a railway vehicle, the more weight each car can carry, which accordingly increases its cargo capacity. In short, raising axle load directly enhances freight transport capability. However, a higher axle load is not always better. Excessive axle loads increase track damage, implying that stronger or more robust rail infrastructure is required to support them.

Since axle load is the weight transferred from the axle to the track, why is it so crucial for heavy-haul trains? In what ways does the axle load of heavy-haul trains differ from that of conventional trains?

To put it simply, for a typical freight car with four axles, the payload can be calculated as $4 \times \text{axle load} - \text{tare (empty) weight of the car}$. If the car weight remains the same, a higher axle load means a greater payload. For this reason, countries with heavy-haul transport mainly seek to increase axle load by lengthening train formations, thereby boosting total transport capacity. In the United States, axle load evolved from 29.8 tonnes per bogie in the 1960s to 32.43 tonnes in 1990 and 35.5 tonnes in 2004. In Australia, the axle load for heavy-haul lines increased from 32.43 tonnes to 40 tonnes. Similarly, Russian heavy-haul train axle load grew from 23.5 tonnes in 1982 to 30 tonnes in 2000. Clearly, axle load is a key driver for the development of heavy-haul trains, but what is the approach to raising axle load effectively?

During the 1970s and 1980s, with the advancement of railway electrification, diesel traction, and the expansion of heavy-haul services, countries placed increasing emphasis on the ratio between axle load and wheel diameter. This is because a higher axle load combined with a smaller wheel diameter increases the stress exerted on the rails. Therefore, maintaining an appropriate proportion between axle load and wheel diameter is crucial; failure to do so may accelerate rail fatigue, speed up track deformation, and jeopardise train operational safety. In 1978, the American Railway Engineering Association (AREA) and Code jointly investigated issues caused by heavy axle loads and small wheel diameters, concluding that a limit must be imposed on the ratio of axle load to wheel diameter (see Table 3).

Table 3: Limits on the Ratio Between Axle Load and Wheel Diameter.

Wheel Diameter (m)	Load per Metre of Wheel Diameter (tonnes)	Permissible Axle Load (tonnes)	Axle Load (tonnes)/ Wheel Diameter (m)
0.710	13.8	19.6	27.56
0.760	13.9	21.2	27.82
0.840	14.3	24.0	28.64
0.950	14.5	26.0	28.88
0.963	14.6	28.4	29.43
1.016	14.07	30.0	29.52
1.167	14.8	31.6	29.62

Source: Selection of Train Axle Load, Speed, and Main Line Parameters.

Next, let's discuss the "length" of heavy-haul trains. Railway transport is divided into long-distance and short-distance operations, though the division is not strictly defined. Conventionally, rail transport within 50 km is referred to as very short-haul, while routes greater than 200 km are considered long-distance transport. In practice, railways spanning less than 200 km are classified as short-distance ones and those exceeding 200 km as long-distance lines. So, how does the "length" of heavy-haul railways differ from conventional train operations, and what advantages does it offer?

Long transport distances are a defining feature of heavy-haul railways. Short-haul distances, coupled with intermediate train marshalling and disassembly, result in slower freight operations. Only with long-distance routes does it become feasible to increase train length and, consequently, the amount of freight carried. Take Canada's heavy-haul railways as an example (see Table 4). In September 1978, two Canadian railway companies opened more than 3,000 km of railway lines to transport coal from the Rocky Mountains in the west to power plants in Ontario in the east, with dedicated heavy-haul trains covering more than 2,000 km. The state-owned railway company undertook a volume of 2 million tonnes over a distance of 2,250 km. To meet the demands of long-distance, high-volume transport, the company extended train formation, deploying ninety-eight open-top coal cars per train formation, each with a capacity of 91 tonnes, with a turnaround time of 7 days per train formation. The other company, the Canadian Pacific Railway, handled a volume of 1 million tonnes over a distance of 2,092 km, operating a train formation of 105 open-top coal cars, each with a capacity of 92 tonnes, and a turnaround time of 6 days per train formation. These examples illustrate how adopting heavy-haul methods for long-distance transport can speed up train turnaround, increase payload per train formation, and thereby reduce transportation costs.

Table 4: Two Canadian Coal Transport Dedicated Lines in 1980.

	Transport Distance (km)	Volume (million tonnes)	Open Cars (number)	Car Capacity (tonnes)	Locomotive Power (hp)	Train Turnaround Time (days)
State-owned	2250	2	98	91	3000	7
Pacific	2092	1	105	91	3000	6

Source: Heavy-Haul Coal Transport Routes of Canadian Railways.

Operating high-capacity heavy-haul trains and increasing train formation require sufficient siding lengths. Heavy-haul railways must have sidings long enough to accommodate the extended train formations needed for these operations. For instance, in 1986, China piloted heavy-haul combined trains on the Beijing–Datong Railway, operating five combined trains daily between Datong and Qinhuangdao, each consisting of two freight train sets with a total payload of 7,400 tonnes. However, because the siding tracks along the transport section were not extended, there was no significant improvement in transport efficiency.³⁰ It can be concluded that the highly efficient operation of heavy-haul trains relies on the extension of the corresponding sidings on railway lines.

Next, heavy-haul trains are characterised by direct operation. “Direct” means unit trains are transported as complete formation, operating as point-to-point, non-stop trains. The unitised heavy-haul train is an innovation in terms of both technology and management of fixed-formation through trains. These fixed-formation through trains operate between terminals without mid-route re-marshalling, though cargo types and cargo owners may vary. The “direct” aspect of unitised heavy-haul trains encompasses the coordination of loading, transport, and unloading operations. Once loaded at the point-of-origin station, the entire train operates without reconfiguration or turning, travels non-stop during transit, and is unloaded as a complete formation at the destination station. In essence, unit train operation treats the locomotive and cars as a single transport unit: loading takes place as a complete set, no re-classification occurs at marshalling yards, and the entire train formation is unloaded directly at the destination, before circulating back for the next transport cycle.³¹ Obviously, the direct operation of heavy-haul trains significantly enhances freight transport efficiency.

³⁰ Zhang Boming [张伯铭], Utilising the Advantages of Rail Transport: Long, Large, Heavy. *Journal of Railway Engineering Society*, no. 1 (1986): 8–13. [发挥铁路运输“长、大、重”优势, 《铁道工程学报》1]

³¹ Lü Shaoxing [吕绍兴], Heavy-Haul Train Transport and Loading/Unloading Facilities. *Port Engineering Technology*, no. 3 (1984): 10–16. [重载列车运输与装卸设施, 《港工技术》3]

Finally, heavy-haul trains are dedicated because they transport a single type of commodity. The first heavy-haul railway built in the United States was primarily designed for coal transportation, and the Soviet Union too developed heavy-haul trains for the same purpose. In contrast, Australia’s heavy-haul systems focus on transporting both iron ore and coal. As for the Da–Qin Railway, heavy-haul trains can transport coal directly from Shanxi’s mining regions to power plants.

Different Approaches to Achieving “Heavy Haul” in Major Countries

Due to variations in operating conditions, types of cargo, and locations of loading and unloading across countries, the specific modes and forms of heavy-haul transportation also differ accordingly. To operate heavy-haul transport, the priority is to increase the weight of train formation, which can be achieved through two approaches: either by adding more freight cars to the train or by raising the load capacity per car. In the 1980s, countries such as the United States, Canada, Australia, Brazil, and some countries in Africa began operating heavy-haul trains, but each country adopted its own distinctive approach, as follows.

North America

The United States and Canada are typical examples of expansion of train formation by increasing the number of freight cars. Their heavy-haul operations primarily use diesel locomotives with an output of 3,000–3,600 hp and a maximum axle load of 32 tonnes. The majority of freight cars used are four-axle types. Since the 1950s, axle loads for heavy-haul trains in the United States have generally been around 30 tonnes, with some trains reaching as high as 36 tonnes. As axle loads increase, so does the load capacity per train. The average load per freight car in the United States rose from 46.4 tonnes in 1950 to 68.6 tonnes in 1977. This increase in axle load necessitated corresponding upgrades in rail and track standards. Consequently, the rail weight on heavy-haul lines in the United States exceeds 65.5 kg/m, and bridge loading standards have been raised to Cooper E-80 class (i.e., maximum axle load of 36.3 tonnes and a uniform load of 11.906 tonnes/m).³²

In the United States and Canada, heavy-haul transportation primarily adopts a unit train model, where overall transport capacity is increased by expanding train formations, and transportation costs are reduced. Their success of heavy-haul operations is largely attributed to the widespread adoption of unit trains. These

³² Sun Baorong [孙宝融], Brief Discussion on Developing Heavy-Haul Transport. *China Railway*, no. 15 (1980): 1–11. [发展重载运输浅议, 《铁道科技动态》15]

trains are composed of a fixed set of locomotives and cars, which function as a single operational unit. They run continuously between loading and unloading stations without the need for intermediate reclassification or rearrangement.

The concept of heavy-haul unit trains originated in the United States and was subsequently promoted throughout North America. As is defined in the United States, a unit train composed of fixed locomotive and rolling stock operates as a single despatch unit and serves as the basis for operational billing, with the goal of maximising tonne-kilometres by increasing the load capacity of both each car and the overall train, apart from accelerating train turnaround, in order to minimise unit transportation costs.³³

Heavy-haul transportation in North America emphasises a high degree of coordination in transport operations. First, there is close coordination among the loading, transportation, and unloading processes. From the loading site to the destination station, the freight is loaded and unloaded without any disassembly or reclassification during the entire process. Upon arrival, automated and mechanised equipment handles the unloading and loading operations. Second, the tractive power of individual locomotives is not exceptionally high; instead, multiple diesel locomotives are commonly used in multiple-unit configurations, sometimes with wireless remote-control technology used to assist locomotive operations. The typical horsepower of standard freight locomotives ranges from 2,000 to 3,000. When wireless remote-control technology is adopted, a train formation can haul more than a hundred loaded cars on steep gradients and around two hundred cars on relatively level routes. In some conventional single-track sections, trains have a high axle load, typically reaching up to 30 tonnes, and use rails weighing 65.5–68 kg/m.³⁴

Additionally, except in challenging terrain where double track is used, most sections generally operate with single-track transport. Overall, the United States, and even the whole of North America, have primarily developed heavy-haul freight by increasing train payloads and optimising technical management.

The Soviet Union

In order to enhance its railway transport capacity, the Soviet Union primarily focussed on developing heavy-haul operations and increasing train density. In 1950, the average load per freight train was 1,430 tonnes, which increased to 2,758 tonnes by 1977. To further expand train transport capacity and boost freight operations, the Soviet Union introduced ultra-heavy and ultra-long trains. By 1979, the traffic density

33 Wu Feng [吴风], Issues on Heavy-Haul Railway Transport. *China Railway*, no. 1 (1984): 1–13. [铁路重载运输问题, 《铁道科技动态》1]

34 Sun [孙宝融], Brief Discussion.

on the Kazan–Domba line had reached saturation. In response to this challenge, the railway administration implemented innovative organisational methods when the station tracks were not extended. On the original infrastructure of railways, they began operating 6,000-tonne heavy-haul trains that travelled directly from one marshalling yard to the next, without any intermediate switching or re-classification. This operational approach significantly improved railway transport efficiency, enabling the Kazan–Domba line to maintain high transport capacity even under saturated traffic conditions. The deployment of such heavy-haul trains not only reduced in-transit dwell time but also lowered transportation costs, making a substantial contribution to the Soviet Union’s railway sector. Subsequently, the Soviet Union developed ultra-long and ultra-heavy trains, raising the average weight of freight trains and unlocking the potential capacity of the rail network. This strategy helped meet the growing demand for freight transport and alleviated capacity constraints on critical sections of the railway.

The first feature of the Soviet Union’s heavy-haul operations is its high load capacities. In 1950, the average load per heavy freight car was 32.3 tonnes, which rose to 62.4 tonnes in 1977. This improvement primarily relied on increasing the size of railcars—adopting four-axle cars with 60- to 63-tonne capacities, some six-axle cars with 94-tonne capacities, and even eight-axle cars with capacities of 120–130 tonnes. Besides, the Soviet Union advanced the modernisation of heavy-haul trains. Emphasis was placed on modernising locomotive power to support heavy-haul transport, deploying high-power locomotives rated between 6,000 hp and 10,000 hp, and pursuing large-scale electrification. Neutral rails were laid on busy sections to extend station tracks and to increase the number of train traction units, and the mainline traction capacity reached around 4,000 tonnes.

The operational mileage of ultra-long and ultra-heavy trains in the Soviet Union steadily increased, whose freight volume accounted for more than 10% of total freight volume. By 1984, rail authorities had run 6,000- to 8,000-tonne ultra-heavy trains and 400- to 800-axle ultra-long empty trains on designated lines, with several lines surpassing a 10,000-tonne train throughput. In 1984, the first 7,000-tonne heavy-haul train entered service on the Baikal–Amur Mainline (BAM). To further increase line capacity, the Soviet Union routinely operated trains weighing 10,000–15,000 tonnes, doubling rail throughput.

There were differences in how the Soviet Union and the United States developed heavy-haul transport. Soviet railcars featured lower axle loads but higher power, and they operated on both single and double tracks. Regarding axle load limits, American freight trains typically had axle loads exceeding 30 tonnes, while Soviet ones generally maintained axle loads between 21 tonnes and 22 tonnes. Locomotive power also differed. Soviet locomotive was notably more powerful, but the United States mostly used single locomotive combinations, with the length of trains typically not exceeding 1.2 km when pulled by the head-end locomotive. Additionally, to address the limitations of single-track operations, the Soviet Union adopted a unique

transport method on certain sections, whereby two trains were combined into one. This approach made it possible to increase transport capacity by 55%–60% over the existing baseline. Trains would depart as single formation or wait to be combined with another on double-track sections; during transit, trains may be reassembled and then separated back into two single formations before arriving at the destination. This allowed sections along the route to accommodate two or more combined trains.

Another difference is the effective extended length of station tracks or sidings. Station tracks refer to all railway lines within a station area, excluding the mainline(s). For heavy-haul trains, station tracks need to be longer than those at regular stations. Compared to the United States, Soviet stations were distributed more densely, with a greater number of departure and arrival tracks along a railway line. As the Soviet Union continually increased both the length and the weight of freight trains, the existing station tracks on older lines became insufficient and required continual extension. By the 1970s, the Soviet railway system had largely completed its modernisation, powered by electric and diesel locomotives. During this period, the Soviet railways adopted train consolidation and the operation of ultra-heavy, ultra-long trains as their primary freight transport methods. This shift significantly enhanced wagon load capacities and transport efficiency. Particularly noteworthy was the operation of a heavy-haul train from Ekibastuz to Tselinograd, which consisted of four regular trains, totalling 440 freight cars with a staggering overall weight of 43,407 tonnes. The successful operation of this heavy-haul train not only demonstrated the Soviet railway's impressive capabilities in technological innovation and transport organisation but also established a new model for railway operations worldwide.

In summary, the operation of ultra-heavy, ultra-long trains and combined trains (i.e., heavy-haul trains) in the Soviet Union was generally based on the reconstruction of existing station tracks, mainline sections, and other related infrastructure. Comprehensive traffic organisation strategies were implemented to effectively address train stopping and passing requirements. On certain congested railway sections, the number of scheduled trains was reduced while train formations were extended, thereby increasing the railway's overall transport capacity.

Australia, Brazil, and South Africa

To transport coal and iron ore, Australia, Brazil, and South Africa built dedicated heavy-haul railway lines from mining areas to coastal ports, and some branch lines or light-rail mainlines were upgraded to accommodate heavy-haul operations.

Australia covers a vast area of 7.7 million km², and by the 1970s, its rail network had reached more than 42,000 km in length. The country's railways feature a variety of gauges, including 1,067 mm, 1,435 mm, and 1,600 mm, creating a complex gauge structure. Railway distribution in Australia was uneven; the southeast coastal regions, especially Victoria and New South Wales, were characterised by a dense rail

network, forming a mesh pattern, whereas railways were sparsely distributed in other more-remote areas. As mineral resources such as iron ore and coal were discovered in southern, western, and parts of central Australia, several dedicated freight railways were constructed to reduce the transportation costs of these mineral resources and building materials.

Initially, Australia operated heavy-haul trains on narrow-gauge tracks. As early as the 1950s and 1960s, the Queensland government undertook technical upgrades on busy mainlines with 1,067 mm narrow gauge, enabling the operation of heavy-haul trains on these lines. A case for analysis is the Hamersley heavy-haul railway, which once served as a reference for the development of Chinese heavy-haul railways. This Australian railway, dedicated to the transport of iron ore, has a total length of 288 km and operates as a single-track line, with the loaded direction primarily on a downhill gradient and a designed axle load of 30 tonnes. Each train is hauled by two locomotives, consisting of 120 freight cars, and the total weight of the whole train reaches 12,000 tonnes. In parts of South Australia and Western Australia, track gauge conversion was carried out, and rail size and axle loads were increased to facilitate heavy-haul operations.

Australia’s heavy-haul railways, on the one hand, leveraged the experience of the United States and Canada, and on the other hand, adapted to the local conditions. The main characteristics are as follows:

First, the axle loads are generally greater than 22.5 tonnes. As illustrated by the heavy-haul mining railways in the Pilbara region (see Table 5), the standard axle load of all the trains is more than 25 tonnes, with the trains being heavy and the iron ore rails large. In the regions of South Australia and Western Australia, gauge conversions were undertaken to enhance heavy-haul freight transport. After the gauge was converted to the standard width in 1957, axle load increased to 20 tonnes. As transport demand grew, L-class locomotives with a 22.5-tonne axle load were later introduced.

Table 5: Mining Railways in the Pilbara Region, Australia.

	Railway Operator	Length (km)	Rail Weight (kg/m)	Standard Axle Load (tonnes)	Train Weight (tonnes)
1	Hamersley Iron Ore	288	59/68	30	18,000
2	Goldsworthy Iron Ore	185	51.6	25.4	40,000
3	Mount Newman Iron Ore	426	65.5	30	18,000
4	Cliffs Robe River	162	59	36.3	90,000

Source: Heavy-Haul Freight Railways Constructed in Australia in Recent Years.

Second, the railway is dedicated to transporting a single type of commodity. Between mining areas and ports, iron ore, coal, and non-ferrous metals are transported by Australia's heavy-haul railways. In Queensland, for instance, a large amount of coal, copper, tin, aluminium, and phosphate, mined from the eastern coastal regions, is transported by new railway lines or upgrades of existing lines.

In addition, operating speeds are relatively low, typically less than 70 km/h, while freight density is high. Trains are mostly of the heavy-haul type, and operations are generally on single-track lines.

In Brazil, South Africa, and other developing countries, dedicated heavy-haul railways are also built from mining regions to coastal ports with the support of foreign investment. In Western Europe, heavy-haul freight trains tend to be shorter and lighter. The tonnage of heavy-haul trains typically ranges from 2,000 tonnes to 4,000 tonnes, with an axle load of around 20 tonnes, and on some lines, it surpasses 5,000 tonnes.

In summary, the approaches to developing heavy-haul transportation vary among the countries mentioned above, each with its own differences in train operation and organisation. In the United States and Canada, locomotives and rolling stock with high axle loads are commonly used, with average train weights ranging from 7,000 tonnes to 13,000 tonnes and maximum weights reaching up to 30,000 tonnes. In addition, these countries, together with Australia, mainly operate unit heavy-haul trains, which operate non-stop in dedicated loops between loading and unloading stations, with only basic maintenance facilities at each terminal. While train turnaround rates are high, traffic density is relatively low. In contrast, the Soviet Union operates long, heavy trains with powerful locomotives to raise average train weights. The heavy-haul trains in Brazil, South Africa, and other countries primarily serve bulk commodity transport; transport routes are usually fixed, often running directly from mines to ports; train formations are operated for direct services whenever possible to improve operational efficiency, with coordinated development of loading, transport, and unloading.

China has its own unique circumstances when it comes to freight transportation. It is important to draw on the strengths of various international practices and develop a heavy-haul model with Chinese characteristics.

The “More Load, Faster Speed” Model of China

After the reform and opening-up, China's demand for freight transportation increased rapidly alongside economic development. However, railway capacity gradually reached its saturation and became a bottleneck that restricted further growth of the national economy. To solve the problem of Shanxi coal's outbound transportation, the Beijing–Datong Railway and Beijing–Qinhuangdao Railway underwent electrification upgrades, but the gap in coal transport capacity was only alleviated

by 38%. A delegation organised by China’s Ministry of Transport conducted overseas inspections of freight transportation in other countries, where they observed that heavy-haul railways offer large transport capacity and low costs. This provided insights for solving the challenge of transporting coal out of Shanxi. In July 1982, the State Council approved the construction of the Da–Qin heavy-haul railway.

Given the unique circumstances in China, the Da–Qin Railway adopted a “More Load, Faster Speed” model with the goal of increasing coal transport volume and improving turnover rates. A key focus during the preliminary research on the Da–Qin Railway was how to localise heavy-haul railways and establish a unique Chinese “More Load, Faster Speed” model.

High Transport Capacity

Projected coal transport volume was a critical factor in the planning and design of the Da–Qin Railway. In China, the uncoordinated planning and construction of coal mines and railways had resulted in low economic efficiency in new railway construction and old-line renovation for many years.³⁵ Determining transport capacity was therefore the primary issue for the design of the Da–Qin Railway. If the designed annual transport volume was set too low, it would only alleviate short-term pressure on coal transport and fail to completely resolve the insufficient railway coal transport in China. On the other hand, if the designed annual capacity greatly exceeded the actual outbound demand for Shanxi coal, it would lead to significant waste of national resources, or in other words, despite heavy investment of manpower and resources, the railway built would turn out to be futile. Thus, the foremost issue in the design of the Da–Qin Railway was to determine the appropriate annual transport capacity.

The initial proposal was 29 million tonnes, with the construction of a conventional line and the deployment of domestically produced “Shaoshan 1” electric locomotives for traction. However, Zhang Hu, then Director of the Planning Department at the Ministry of Railways, put forward a target annual transport capacity of 100 million tonnes. This new proposal means that, disregarding any impact of adverse weather, operational accidents, or other factors, 270,000 tonnes of coal would be transported each day from Datong to the port of Qinhuangdao. Such a proposal was indeed appealing, as daily outbound transport of 270,000 tonnes of Shanxi coal would significantly alleviate China’s energy crisis and relieve the pressure on the railway network. However, at the time, Canada’s Labrador Line had an annual transport capacity of around 40 million tonnes, Australia’s Hamersley Line reached 40 million tonnes, too, and the Soviet Union’s largest rail line, the Baikal–Amur Mainline,

35 Duan Liu [段颢], Railway Design & Construction and Coal Transport Volume. *Railway Standard Design*, no. 3 (1988): 1–9. [铁路设计和建设与煤炭运量, 《铁道标准设计通讯》3]

handled only 35 million tonnes/year. For a designed annual transport capacity of 100 million tonnes, would there be enough Shanxi coal to transport? More importantly, would China be able to achieve those technical breakthroughs in heavy-haul transport?

Determining the transport capacity for the Da–Qin Railway could not be accomplished by relying solely on desk-based analysis. To know the accurate coal transport volume, the investigation team needed to conduct hands-on field research and make coal production forecasts during the surveying, design, and construction phases of the mining areas. As a result, the technical team undertook on-site investigations, travelling from the Yungang Mine in Datong to the Xishan Mine near Taiyuan. Their research found that, in the northern Shanxi region—including Datong Mining Bureau, Pingshuo open-pit coal mine, and eleven local county mines—the total coal output was expected to exceed 100 million tonnes in 1990. Some scholars even predicted that Shanxi Province’s annual coal production would reach 400 million tonnes in 2000. Besides, coal from the western part of Inner Mongolia, as well as Shaanxi and Ningxia, also needed to be transported eastwards by railways via Datong, and coal output would far exceed the capacities of the existing rail network.

Specifically speaking, it was projected that outbound coal shipments on the northern route of Shanxi Province would reach 117 million tonnes in 1985, of which the Da–Qin Railway would transport 54 million tonnes. With the development of Shanxi’s energy base, coal from Zhunge’er, Inner Mongolia, transported via the Datong–Zhunge’er Railway, was projected to reach 11 million tonnes in 1995 and 17 million tonnes in 2000. Furthermore, coal shipped out from Shenmu, Shaanxi, was expected to hit 20 million tonnes in 1995 and 57 million tonnes in 2000. Thus, the combined outbound coal volume from the “Three Western Regions” would reach 150 million tonnes in 1995 and 235 million tonnes in 2000.

To support the operation of heavy-haul unit trains on the Da–Qin Railway, eighteen coal consolidation stations were established around Datong City, in northern Shanxi. Once all these stations were established, the annual coal transport volume could reach 90.6 million tonnes (the designed scale and mechanised loading capacity of each station, see Table 6). Since Datong had ample coal supply to meet demand, it was entirely feasible to design the Da–Qin Railway with a long-term target capacity of 100 million tonnes.

To achieve the annual transportation target of 100 million tonnes for the Da–Qin Railway, the final design accommodates the operation of thirteen 10,000-tonne trains and thirty-six 6,000-tonne trains, in coordination with adjacent railway operators. Other trains are designed for 4,000-tonne capacity, and the maintenance window is set at 160 min. Under this plan, the annual throughput capacity would reach approximately 110 million tonnes. However, considering station capacity coordination, an annual transport volume of 100 million tonnes is deemed practical

and achievable.³⁶ In terms of coal supply and railway operational planning, an annual transport capacity target of 100 million tonnes on the Da–Qin Railway was entirely viable.

Table 6: Overview of Eighteen Coal Consolidation Stations in Northern Shanxi.

Serial Number	Loading Points	Design Capacity (10,000 tonnes)	Suitable Loading Capacity (tonnes)
1	Luoliwan	450	10,000
2	Nanyao	400	10,000
3	Sitaigou	550	10,000
4	Yanzishan	500	10,000
5	Que’ershan	200	4,000
6	Yangfangkou	300	4,000
7	Ningwu	450	4,000
8	Antaibao	2,130	10,000
9	Shangshenjian	360	10,000
10	Xinggaoshan	350	6,000
11	Jinshatan	400	10,000
12	Beizhouzhuang	400	10,000
13	Liujiakou	400	10,000
14	Muguajie	450	10,000
15	Dianwan	200	10,000
16	Yungangxi	520	10,000
17	Jinhuagong	400	4,000
18	Dongzhouyao	600	10,000

Source: Datong–Qinhuangdao Railway.

³⁶ Da-Qin Railway Construction Office of the Ministry of Railways [铁道部大秦铁路建设办公室], *The Datong-Qinhuangdao Railway* (China Railway Publishing House Co., Ltd., 1995), 53. [《大秦铁路》。中国铁道出版社]

Efficient Train Operations

In the 1980s, China began experimenting with high-powered locomotives and increased train weight on busy railway lines. For instance, on railways such as Beijing–Datong, Beijing–Qinhuangdao, and Shenyang–Shanhaiguan, 5,000-tonne trains and combined trains were operated. Although certain economic results were achieved, the combined heavy-haul trains were not significantly effective due to limitations in station track length and rolling stock. Drawing on the experience from both domestic and international heavy-haul transport, the Da–Qin Railway adopted a “More Load, Faster Speed” operation model. It operates unit trains loaded in their entirety at the origin, with full-train loading and unloading to minimise loading time and reduce intermediate marshalling. Unlike the heavy-haul railways in countries such as the United States, the Da–Qin Railway connects with other lines to operate two pairs of passenger trains and two pairs of pick-up/drop-off freight trains. Therefore, the Da–Qin Railway is not solely a dedicated heavy-haul coal railway but rather functions as a mixed-traffic railway, primarily relying on unit trains while also accommodating passenger and freight co-transportation.

The Da–Qin Railway organises operations based on the principles of (i) “coordination of loading, transporting, and unloading” and (ii) long-term coal export volumes. It operates on a closed-loop system with permanently coupled train sets, uninterrupted round-trip cycles, and no en route modifications to train cars, axles, or locomotives, shuttling continuously between Datong as the origin station and the Qinhuangdao Port Phase III Coal Terminal. As speed is one of the hallmarks of China’s heavy-haul railways, in addition to the aforementioned practice, how can the Da–Qin Railway improve turnaround efficiency in train operation management?

First, except for essential scheduled stations, trains do not stop or yield to other trains en route. This principle of minimising intermediate stops marked a significant breakthrough in China’s train operation management. Certainly, the relatively dense distribution of stations along China’s main railway lines is related to the widespread use of concrete sleepers at the time. In contrast, the United States predominantly uses steel rails, with tracks often overgrown with weeds, but since their primary goal is coal transportation, they disregard such issues as long as coal shipments remain unaffected. As long as the rails and roadbed can bear the load—and there is enough cargo—they load trains to the absolute limit: if one locomotive cannot pull the load, they use two; if two cannot, they use four; if four fail, eight are used! There are even cases where a single freight train utilises up to fifteen locomotives.³⁷

Train operation management of the Datong Railway must be bold in breaking outdated norms and be firmly centred on transport efficiency. It is widely understood that the more the stations that are set up, the more limited the train throughput

37 Zhou and Liu [周文斌, 刘路沙], *Black Gold Channel*, 56.

becomes. However, the conventional practice in China was that stations were typically placed every 7–8 km. If the Da–Qin Railway had followed this conventional practice, coal transport efficiency would have been severely reduced. The main purpose of the Da–Qin Railway is to transport coal. The distance between stations can be appropriately extended, and only if coal transport is not affected can passenger services be considered.

Second, train operation management must consider the specific conditions of China. As the design specifications for the Da–Qin Railway explicitly states, “This railway is designated as a dedicated coal transport line, primarily operating heavy-haul unit trains to maximise transport capacity. Accordingly, the design allows for only two pairs of conventional passenger trains and two pairs of pick-up/drop-off freight trains per day, with all other passenger and freight traffic continuing to use existing lines.”³⁸ The station distribution and operational design of the Da–Qin Railway incorporate two key principles: strategically setting up stations of technical inspections and maintenance; balancing regional economic development while minimising intermediate stops and simplifying station facilities. Accordingly, between Datong and the Qinhuangdao Coal Terminal, designated freight pickup/drop-off points are established at Datong, Yangquan, Zhuolu, Pinggu, Yutian North, Zunhua North, Lulong North, and Funing North.

Unlike the heavy-haul railways in the United States and Australia, which mainly pass through sparsely populated areas, with few intermediate stations, the Da–Qin line runs through densely populated and extensively farmed regions. At that time, China’s rail capacity was saturated, making both passenger and freight transportation difficult. Consequently, the Da–Qin Railway served as a dedicated coal transport line, but it also partially accommodated regional passenger and freight services, allocating a portion of its capacity to ease transportation challenges along the line and support local economic development.

Third, turnaround efficiency of unit trains and unloading operations must be enhanced. Measures are taken to streamline processes at both stations and Qinhuangdao Phase III Coal Terminal. As soon as a loaded train is unloaded, an empty train is promptly assembled, significantly reducing port dwell time and operational delays. A centralised, unified command system governs unloading operations to ensure seamless coordination: the Qinhuangdao Coal Terminal is managed by the railway administration; unloading operations are supervised by the transportation administration; tippler systems are constructed by the Qinhuangdao Port; railway components are built and maintained by the railway authority; and railway and port authorities only engage in freight exchange.³⁹ In a word, this unified despatching

³⁸ Da-Qin Railway Construction Office of the Ministry of Railways [铁道部大秦铁路建设办公室], *The Datong-Qinhuangdao Railway*, 271.

³⁹ Da-Qin Railway Construction Office of the Ministry of Railways [铁道部大秦铁路建设办公室],

system enables centralised command, streamlined handovers, and operational efficiency, ensuring seamless coordination among railway, port, and mining sectors.

Fixed-formation, circulating through trains are operated among ports, power plants, and coal distribution hubs. The overall “loading–transport–unloading” workflow is implemented on the Da–Qin Railway. First, eighteen coal consolidation stations are set up around Datong. Heavy-haul trains (with loads of 10,000 tonnes) pass through the loading stations at a speed of no more than 1 km/h. Once fully loaded, the trains are directed immediately onto the Da–Qin Line, heading non-stop to the Qinhuangdao terminal in the east. Upon arrival, trains are not disassembled but are instead unloaded as a full train formation at the Phase III Coal Terminal. The empty train formation then returns to the coal loading points in Datong, where they are reloaded. This cycle is repeated continuously, forming a seamless loop transporting Shanxi coal from Datong to the central-eastern and coastal regions of China via Qinhuangdao.

Aligning the Route as Straight as Possible

After the preliminary planning of the Da–Qin Railway was completed, the alignment of the route became a major challenge. Regional planning along the line, opinions of local governments and residents, complex geological conditions (including mining subsidence areas), difficult terrain, and military zones all influenced the route selection.

The engineers’ ideal was simple. “The straighter and shorter, the better! If we could draw a straight line on the map like an air route, that would be perfect!”⁴⁰ But real-world constraints made this impossible. The key debate centred on three critical sections: the Sanggan River Gorge, the Jundu Mountain Tunnel, and the Yuqiao Reservoir. Should the line detour? What would it cost to operate? What would local governments think? The design team agonised over whether they should stick to the principle of making the line as short and straight as possible.

In reality, the design team faced two route options. The first was the route via the Dayang River in the north. This option features flatter terrain, simpler geological conditions, lower construction costs, and easier engineering. However, this detour would extend the total railway length by 40 km.

The other option was the route through the Sanggan River Gorge, which had complex geological conditions and significantly higher construction challenges. This gorge lies within the Sanggan River Fault Zone, where intense tectonic compression has violently uplifted the terrain and caused severe ground deformation. The river

The Datong–Qinhuangdao Railway, 53.

⁴⁰ Zhou and Liu [周文斌, 刘路沙], *Black Gold Channel*, 73.

channel winds through narrow bends with steep gradients where some areas exhibit a relative elevation drop exceeding 600 m. Combined with deep fracture zones, the gorge has earned the nickname “Geological Museum” among geological survey scholars. The banks are also prone to mudflows, floods, and landslides. Consequently, some geological surveyors once questioned the logic of building a railway via the Sanggan River Gorge.

Yet, this route offered a straighter path that shortens the Da–Qin Railway by dozens of kilometres. If the Railway were extended by 10 km per coal trip, and fifty trains operated per day, this would amount to an additional 500 km/day—equivalent to 200,000 km annually, roughly four times China’s total rail length at the time. Moreover, China’s railway was carrying out the “all-inclusive contract system,”⁴¹ and the national railway investment was relatively insufficient. Unlike North America’s budget-unconstrained approach, the design team must take into consideration the project funding and, in consequence, would not like to easily give up the route via the Sanggan River Gorge.

The Third Survey and Design Institute of the Ministry of Railways was responsible for surveying the geological structures of the Sanggan River Gorge and the Dayang River. The institute mobilised 70% of its workforce, deploying a total of six survey teams, two geological teams, and one specialised aerial survey team to conduct the surveying work. The massive manpower investment in surveying the terrain of the Sanggan River Gorge aimed to ensure that the Da–Qin Railway would be as straight as possible, because shortening the line by dozens of kilometres would significantly reduce future operational costs.

The alignment design near Yuqiao Reservoir also posed a significant challenge. Initially, the Da–Qin Railway was planned to pass several hundred metres downstream of the Yuqiao Reservoir dam. However, Tianjin Municipality raised concerns that the continuous operation of coal trains could threaten the structural integrity of the dam and that coal dust might pollute the water source, proposing that the Da–Qin Railway be rerouted. With an annual freight volume of 100 million tonnes, extending the route by 9 km would result in an additional 900 million tonnes/km of transportation costs per year. Although the railway posed minimal risk to the water source and negligible threat to public health, Tianjin Municipality placed an exceptionally high priority on water protection. After extensive deliberation between the Ministry of Railways and Tianjin Municipality, both sides adhered firmly to their principles of serving the people: the Ministry insisted on minimising route length to reduce costs, while Tianjin maintained its commitment to the highest standards for water source protection.

41 The “all-inclusive contract system” (*Da Bao Gan*) refers to a system followed in China during the 1980s, which assigns full responsibility for costs, tasks, and profits to individual households or enterprises. —Translator’s note.

Ultimately, the Ministry of Railways decided that the railway would detour around Yuqiao Reservoir.

The construction of any railway is never smooth sailing, as it requires balancing the interests of all stakeholders along the route, and the Da–Qin Railway was no exception. Running through Beijing, Tianjin, and Hebei, it required large-scale land acquisition. Although its design prioritised a straight and direct route, complex realities during planning and surveying made detours necessary to protect the interests of local communities.

Advanced Technical Standards

As China's first modernised, double-track electrified railway dedicated to heavy-haul unit trains, the Da–Qin Railway must adopt cutting-edge technologies, equipment, and processes.

Building such a high-standard, modern railway posed an immense challenge for designers, as there were no existing precedents to follow.

First, while the global rail industry was transitioning to electrification, choosing electric locomotives for the Da–Qin Railway was the right decision. However, at the time, no electric locomotive in the world had the power to haul 10,000-tonne trains. The first major hurdle was how to synchronise multiple locomotives for combined traction. Due to the 10,000-tonne train's massive inertia and impact forces during operation, another problem was how to innovate the braking system. Then came the heavy-haul track structure. The Da–Qin Railway bears vastly greater axle loads and cargo weights than conventional freight railways, which would severely accelerate track degradation. Power supply was another hurdle. China lacked suitable high-capacity transformers, requiring the Railway to adopt cutting-edge remote monitoring and control systems. Furthermore, the existing overhead catenary systems and components were incompatible with the Da–Qin Line's demands. How to ensure the heavy-haul trains' safe operation in the mountainous terrain was also a problem. As the project advanced, technical problems and challenges emerged one after another.

Preliminary research estimated that more than ninety major technological breakthroughs needed to be made. The challenges were not merely technical; after the completion of Phase I with imported equipment, Phase II demanded full localisation, necessitating breakthroughs within tight deadlines. Moreover, uncertainties lingered over whether the nation would firmly support the construction of such a highly modernised railway. Given the fact that China's existing rail tracks, locomotives, and rolling stock were not usable for this new railway, massive foreign currency expenditure was needed to import equipment and undertake technological innovation. However, as coal transport pressures intensified and the advantages of heavy-haul operations became undeniable, the State Council mandated that the National Leading Group for Major Technical Equipment assume responsibility for the

systematic import and deployment of the Da–Qin Railway’s integrated technology and equipment portfolio. The goal was to build this railway into a dedicated, high-capacity coal corridor characterised by high quality, fast speed, efficient investment, high returns, and minimal intermediate stations.

Developing heavy-haul trains demands a comprehensive system encompassing rails, extended station tracks, locomotives/rolling stock, signalling, power supply, operational coordination, and synchronisation among railways, mines, and ports. Thus, Da–Qin’s success must depend on comprehensive, integrated technological innovation. It cannot rigidly replicate the transportation models of other countries. Instead, it must forge its own path based on China’s existing technologies, rail network distribution, cargo flow patterns, port handling capacity, and other realities. This requires synthesising the strengths of international practices while aligning with national conditions. Notably, before the Da–Qin Railway’s construction, China had piloted heavy-haul operations on the Beijing–Datong and Beijing–Qinhuangdao Railways to accumulate experience. Beyond core technologies, successful heavy-haul operations require stable coal supply sources, optimised train marshalling, and seamless rail–mine–port integration. Each element in this interconnected system is critical, collectively shaping Da–Qin’s unique “More Load, Faster Speed” model.

First, ensuring a concentrated and stable coal supply source is essential. Internationally, countries operating heavy-haul freight—whether it is the United States, the Soviet Union, Australia, Brazil, or South Africa—primarily focus on coal transportation. At that time, coal accounted for 40% of China’s railway freight volume, with Shanxi Province alone contributing about a quarter of the nation’s total coal shipments. The coal transportation challenges in Shanxi mirrored those in the United States and the Soviet Union.

However, unlike these countries, Shanxi’s coal resources were decentralised. Local mines were scattered, coal varieties were diverse, and shipments of coal from the Datong Mining Bureau reached more than twenty provinces and municipalities. This lack of centralisation hindered the fixed-formation, cyclical operation of heavy-haul trains. To solve this problem, eighteen coal consolidation stations were established near Datong, where coal transported via regional rail lines was collected before being shipped via the Da–Qin Railway to Qinhuangdao Port. In the long term, the operation of heavy-haul trains was contingent on reliable supply sources, which in turn promoted the development of Shanxi’s coal base.

Second, the train formation adopted a unit train system with double-track bidirectional operation. The Da–Qin Railway implemented the unit train model inspired by the United States, which features whole-train loading and unloading. However, given China’s limited heavy-haul technology at the time, it did not replicate the U.S. approach of increasing axle loads. Instead, the Da–Qin Railway leveraged modern loading/unloading equipment to minimise transit and idle times. A key feature was the non-stop operation, i.e., no en-route decoupling or re-marshalling of locomotives and train cars.

The supporting facilities for the Da–Qin Railway include coal consolidation stations located in Datong and Yanbei, as well as the Phase III Coal Terminal at Qinhuangdao Port. These are critical factors that enabled the operation of heavy-haul unit trains on the Da–Qin Railway. For one thing, the operation of heavy-haul unit trains is only feasible if the coal transport volume from the coal consolidation stations matches the minimal requirement of water transport via the Phase III Coal Terminal at Qinhuangdao Port. Otherwise, due to the requirements of unloading electrification infrastructure, only conventional trains can be deployed. For another, the equipment conditions at the coal unloading points of the Da–Qin Railway were also upgraded. In 1985, the Qinhuangdao Phase I and Phase II Coal Terminals were completed, significantly enhancing the port’s coal-handling capacity. Subsequently, the Phase III Coal Terminal was also built in parallel with the development of the Da–Qin Railway.

For the “More Load, Faster Speed” model, it is essential to integrate production, transport, and unloading, in addition to coordinating loading, transport, and unloading. The loading capacity of the Datong consolidation stations determines the Railway’s annual throughput, while the discharge capacity of the Qinhuangdao Port’s Phase III Coal Terminal affects the Railway’s transportation management. This highlights the Da–Qin Railway’s complex system-wide operations, which extend far beyond mere rail construction. To optimise performance, coal flow must be meticulously planned. In other words, heavy-haul trains should be arranged in advance and, upon arrival at Qinhuangdao Port, the coal should be distributed as planned. Consequently, rail transport alone is insufficient; seamless integration with road and waterway networks is critical. As a large-scale systemic project, the Da–Qin Railway needs to coordinate with the coal consolidation stations in Datong and Yanbei, as well as the Phase III Coal Terminal at Qinhuangdao Port. A strategic, system-wide mindset was deemed necessary for success.

Finally, the selection of heavy-haul technology was critical. As the Da–Qin Railway’s technical specifications require, upbound unit trains are designed to haul 6,000 tonnes (10,000 tonnes as the long-term target) and downbound trains 2,350 tonnes. The locomotive must have sufficient tractive force and braking capacity to ensure safe operation on steep gradients. For this reason, the Da–Qin Railway adopted electric locomotives as the main traction power—a key distinction from the U.S., Canadian, or Australian heavy-haul systems. It is also a major advantage of China’s heavy-haul railway, because electric traction could significantly reduce transport costs. The calculations of American companies reveal that electric locomotives cost 50% less in maintenance than diesel ones, and electricity was cheaper than fuel.

During the period of China’s Sixth Five-Year Plan, 5,000-tonne heavy-haul trains were successfully operated. The experimental data analysis indicates that China’s domestically manufactured diesel locomotives succeeded in forming heavy-haul trains. However, to operate 10,000-tonne freight trains on the Da–Qin Railway, it remained necessary to continue introducing foreign technology and to overcome technical challenges concerning locomotives. On the other hand, this also

demonstrates that numerous technical obstacles are not insurmountable, and China is capable of achieving the localisation of heavy-haul technology.

According to the design brief approved by the State Council, “The Da–Qin Railway represents a major innovation in railway equipment and transport management,” another technically intensive railway project after the completion of the Chengdu–Kunming Railway. In every phase—design, construction, and operation—the Da–Qin Railway was tailored to China’s specific conditions and built into a modern railway with Chinese characteristics. This has resulted in technological innovations in railway transportation management, heavy-haul technology, and civil engineering, establishing a new model for the modernisation of China’s railway freight transport.

In the end, the Da–Qin Railway achieved a major leap in China’s heavy-haul technology by utilising fifty-one domestically developed technologies and thirty-five foreign-introduced technologies in the contexts of traction, rolling stock, track engineering, signalling & communications, power supply, and transportation operations.