

Chapter 4

The World's Highest-Capacity Heavy-Haul Railway After Upgrade

With the gradual operation of 5,000-tonne and 6,000-tonne heavy-haul trains on the Da–Qin Railway, its annual freight volume reached 100 million tonnes in 2002 and 120 million tonnes in 2003. The line's transport capacity was approaching saturation, while demand for coal transportation continued to rise. In response, the Da–Qin Railway actively collaborated with the Datong Railway Bureau, the Beijing Railway Bureau, and the Qinhuangdao Coal Terminal to increase freight volume by adopting heavy-haul technologies. However, relying solely on tapping the existing transport potential cannot fundamentally solve the problem—the very reason behind China's initial decision to construct the Da–Qin Railway. Ultimately, the government approved its 200-million-tonne heavy-haul capacity expansion project.

From 2003, the Da–Qin Railway carried out its capacity upgrades. Instead of simply adding more train cars in the traditional way, it relied on a dual approach of technological and managerial innovation. The technological innovation covered the adoption of new open-top coal cars, Harmony-typed high-power locomotives, locomotive synchronisation control technology such as Locotrol,⁷¹ and advanced communication technologies to increase the hauling capacity. Transport management along the Da–Qin line was optimised to ensure smooth operation and improve transport efficiency. As a result, the 200-million-tonne capacity expansion project became a landmark for the leapfrog development of China's railway, a model for modern heavy-haul coal corridors, and a benchmark for capacity upgrades on existing railway lines.

China's Coal Transportation Situation in the 21st Century

“Three Western Regions” Remaining the Key Coal Transportation Base

In the 21st century, new energy sources have gradually gained momentum, yet coal remains the primary energy source in China. In 2002, coal accounted for 66.1%–70.7% of China's energy consumption structure, followed by crude oil (7.2%–23.4%), natural gas (2.7%–3.2%), and hydropower/nuclear power (7.8%–8.9%). The data provided by China's power companies reveal that coal for power generation increased by 50 million

⁷¹ Locotrol is defined by Wikipedia as “a product of Wabtec Corporation that permits railway locomotives to be distributed throughout the length of a train (distributed power). It is installed on more than 20,000 locomotives around the world, sending signals from the lead locomotive and via radio to the remote control locomotives”. See <https://en.wikipedia.org/wiki/Locotrol>. —Translator's note.

tonnes in 2001 and 80 million tonnes in 2002 compared to the previous years, and China's total coal demand would continue to rise steadily over the next 2 decades. According to historical data statistics, for every one percentage point increase in China's gross domestic product (GDP), coal consumption grew by two percentage points, which again displayed the central position that coal would continue to occupy in the long term.

As of 2002, the proven coal reserves in the “Three Western Regions” totalled approximately 550.1 billion tonnes, accounting for around 55% of China's total proven coal reserves. Thus, this region remained a major base for coal production and outbound transportation. Specifically, in 2002, Shanxi Province produced 412 million tonnes of coal, consumed 109 million tonnes locally, and had a net outflow of 303 million tonnes; Shaanxi Province produced 84 million tonnes, consumed 38 million tonnes, and exported 46 million tonnes; Inner Mongolia produced 115 million tonnes, consumed 52 million tonnes, and shipped out 63 million tonnes.⁷² According to national projections at the time, coal production in the “Three Western Regions” would reach 880 million tonnes by 2010, 1,050 million tonnes by 2015, and 1,200 million tonnes by 2020, with estimated railway outbound transport volume of 610 million tonnes, 760 million tonnes, and 880 million tonnes, respectively (see Table 7). As a result, outbound coal transport corridors from the “Three Western Regions” remained a key focus of national railway construction.

Table 7: Coal Production and Outbound Transportation in the “Three Western Regions” (unit: 10,000 tonnes)

Year	2000	2001	2002	2010*	2015*	2020*
Production	43,262	48,060	56,050	87,560	105,410	119,820
Consumption	16,497	16,430	19,200	25,500	29,100	31,000
Net Output	26,765	31,630	36,850	62,060	76,310	88,820
Railway Outbound Volume	24,147	27,685	32,762	61,410	75,600	88,170

* The data are based on projections.

Source: The Third Corridor for Coal Transportation in the “Three Western Regions.”

⁷² Wang Dongming [王东明], On the Third Channel of Transporting Coal from “Three Western Regions”. *China Transportation Review*, no. 9 (2004): 15–17. [三西煤炭运输的第三通道问题, 《综合运输》9]

Owing to the continuous construction of railway infrastructure since the 1980s, outbound coal shipments from the “Three Western Regions” rose from 184.38 million tonnes in 1990 to 226.36 million tonnes by 2000. Entering the 21st century, the outbound transport of coal from the “Three Western Regions” relied on three major corridors: northern, central, and southern.

The northern corridor included the Da–Qin Railway, the Beijing–Shacheng Railway, the Shuozhou–Huanghua Railway, and the Jining–Tongliao Railway. It handled 60% of the total coal shipments from the “Three Western Regions,” primarily transporting coal from northern Shanxi, western Inner Mongolia, and northern Shaanxi. Notably, the Da–Qin Railway alone accounted for around 60% of the coal throughput within this corridor.

The central corridor comprised the Shijiazhuang–Taiyuan Railway and the Handan–Changzhi Railway.

The southern corridor consisted of the Taiyuan–Jiaozuo Railway, the Houma–Yueshan Railway, the Nanjing–Xi’an Railway, and the Xi’an–Ankang Railway.

The Da–Qin Railway first transported coal from Shanxi Province and gradually expanded its coverage to the entire “Three Western Regions.” In Shaanxi Province, coal transportation gradually shifted from the Ningwu–Kelan Railway to the Shenhua Railway network (the Shuozhou–Huanghua Railway as its core line), connecting to the Da–Qin Railway. The network’s annual outbound volume reached 6.3 million tonnes by 1998, accounting for 11.6% of the Da–Qin Railway’s total capacity. Additionally, coal from Ningxia and Inner Mongolia was increasingly redirected to the Datong–Zhunge’er Railway, feeding into the Da–Qin Railway, which tripled annual volume compared to earlier years. By 2002, the Da–Qin Railway maintained an annual capacity of around 100 million tonnes, while the Shuozhou–Huanghua Railway handled approximately 4 million tonnes. According to coal transport projections at the time, the Da–Qin Railway was expected to expand to 375 million tonnes by 2020—a conservative estimate, as its actual capacity reached 400 million tonnes as early as 2008.

Insufficient Coal Transport Capacity

Since the Da–Qin Railway was fully opened in 1992, it has been continuously transporting coal. Its western end connects with the Datong railway hub, linking coal production bases in northern Shanxi, Shaanxi, and western Inner Mongolia (the “Three Western Regions”), while the eastern end connects to Qinhuangdao Coal Terminals (Phases III and IV). With thirty-three stations along the entire line, the Da–Qin Railway can accommodate 10,000-tonne heavy-haul trains but has long been operating at full capacity.

Relevant data show that since its opening, the annual coal transport volume on the Da–Qin Railway has grown by 10% each year. By 2003, cumulative coal shipments had

reached 820 million tonnes. Look at specific years: in 2000, train operations between Hanjialing and Dashizhuang reached eighty freight pairs and three passenger pairs daily, with maximum freight density hitting 89.78 million tonnes—fully utilising its capacity. In 2002 and 2003, freight volume surged to 103.4 million tonnes and 126.91 million tonnes, respectively, far exceeding the designed capacity.

Meanwhile, as China's economy continued to grow, the national demand for coal transportation increased, with energy constraints becoming increasingly prominent. In the first half of 2003, China's GDP grew by 8.2%, yet electricity consumption surged by 15.43%,⁷³ reflecting the economy's heavy reliance on energy. Due to insufficient power supply, large-scale power shortages (a so-called "electricity famine") occurred in 2003, spreading from local areas to the entire nation. In the summer of 2003, high temperatures triggered rolling blackouts in many places, including the Yangtze River Delta region. Jiangsu Province faced a 4.15-million-kW power deficit, while Shanghai alone experienced a 600,000-kW shortage on July 21. In the winter of the same year, coal supply shortages and extreme cold led to power shortages in eight provinces.

To ensure stable coal supply and sustain economic development, the Da-Qin Railway was pushed beyond its limits. Originally designed for 100 million tonnes/year of coal, it handled 120 million tonnes in 2003 and 150 million tonnes in 2004. Under the circumstance of saturated railway transport capacity in other railways (e.g., Shijiazhuang-Taiyuan, Beijing-Datong, Beijing-Yuanping), and given the challenges in the capacity expansion of Huanghua Port on the Shuozhou-Huanghua Railway, the responsibility of transporting more coal out of Shanxi Province naturally fell upon the Da-Qin Railway.

Consequently, the capacity expansion and modernisation of the Da-Qin Railway became the indispensable choice for enhancing coal transport capacity in China during the 21st century. Coal resources, coal-fired power, Shanxi coal transport, and the Da-Qin Railway once again captured national attention.

In 2004, in line with the overall requirements of China's economic development, the Ministry of Railways, after thorough deliberation, proposed a capacity expansion plan for the Da-Qin Railway. Building upon its existing 100-million-tonne capacity, the plan aimed to increase its annual transport volume to 150 million tonnes, with a further target of reaching 200 million tonnes by 2005.

Necessity of Capacity Expansion

As an integral part of the entire outbound Shanxi coal transportation system, the Da-Qin Railway cannot simply increase the volume of coal transported by rail if it

⁷³ Unknown Author [作者不详], Behind the "Electricity Shortage". *China Machinery and Electric Industry*, no. 17 (2003): 7. [“电荒”的背后, 《中国机电工业》17]

expands its capacity. It requires a comprehensive consideration of the potential capacities of three aspects, i.e., railway lines, coal mines, and ports. Next, from these three aspects, let's analyse why it is necessary to expand the Da-Qin Railway's capacity to an annual transport volume of 200 million tonnes.

First, regarding the mines, is the coal supply from Shanxi, or the source of freight for the Da-Qin Railway, sufficient? As has been mentioned earlier, since the beginning of the 21st century, the outbound transportation of coal from Shanxi has gradually increased. Does this imply that the outbound transport volume on the Da-Qin Railway will also increase? To what extent will it increase, and does this justify the need for the Railway's capacity expansion? Is the outward transport volume consistent with the annual transport volume? These questions are essential, for coal production and transport volume have a significant impact on the necessity of the Railway's capacity expansion.

Coal remains the primary energy source for China's economic development, a fundamental reality that will persist in the long term. Analysis of global energy consumption structure reveals that nations invariably rely on their most abundant indigenous resources to shape their energy mix. China possesses substantial coal reserves. In 1998, energy agencies estimated the country's recoverable coal reserves at 114.5 billion tonnes, compared to 3.8 billion tonnes of technically recoverable oil and 1.37 billion m³ of natural gas. Consequently, a coal-centric energy framework is essential to ensuring stable energy development in China.

Since the 1990s, economic restructuring, such as prioritising energy efficiency, emission reduction, environmental protection, and renewable energy development, has gradually reduced coal's share in the national energy mix (from 71.5% in 1997 to 67% in 2000). Forecasts suggest that its proportion may decline to 60% by 2020 and 50% by 2050, but absolute demand continues to rise, and coal will remain China's dominant primary energy source, as both domestic and international experts project. This trend can be exemplified by coal-power statistics. In 2005, China's total electricity generation reached 2.47 trillion kWh, a 23.6% year-on-year increase, with coal-fired power accounting for 2.01 trillion kWh (approximately 80% of the total). This underscores that coal-dependent power generation will persist as the norm in the foreseeable future.

Second, regarding the railway, the Da-Qin Railway has long maintained a stable volume of coal shipments. While the "Three Western Regions" account for roughly one-third of the nation's coal production and about two-thirds of outbound coal shipments, the Da-Qin Railway handles about one-third of that outbound volume. During the first decade since its operation, the Da-Qin Railway gradually formed a coal transport network centred on Datong, with its reach steadily expanding westwards and northwards. The 2003–2004 coal transport structure of the Da-Qin Railway (see Table 8) shows that the Datong–Taiyuan Railway handled 54.75 million tonnes that year, accounting for 45.67% of the total volume on the Da-Qin Railway, and this volume rose to 74.15 million tonnes in 2004, accounting for 49.23% of the

total volume. The Datong–Baotou and Datong–Zhunge’er lines maintained around 8% of the total volume. Clearly, the coal collection and distribution centres near the Datong–Taiyuan Railway and the Datong hub are key to organising rail traffic on the Da–Qin Railway.

Table 8: Sources of Coal Transport Volume on the Da–Qin Railway.

Source	2003		2004	
	Volume (10,000 tonnes)	Percentage of Total Volume (%)	Volume (10,000 tonnes)	Percentage of Total Volume (%)
Datong–Taiyuan Line	5,475	45.67	7,415	49.23
Datong Hub	4,774	39.82	5,172	34.34
Datong–Baotou Line	493	4.11	591	3.92
Datong–Zhunge’er Line	986	8.22	1,465	9.72
Along Da–Qin Line	219	1.83	401	2.66
Others	41	0.34	16	0.11

Source: Da–Qin Heavy-Haul Railway Transportation Technology.

In addition, the Da–Qin Railway also serves nineteen coal transportation enterprises operating on the Datong–Taiyuan Railway, the Yungang Branch Line, and the Kouquan Branch Line. Among them, eleven have coal production capacity, while the remaining eight purchase coal from local sources. This demonstrates that the Da–Qin Railway has established a long-term cooperative coal enterprise network. In fact, the Da–Qin Railway is responsible for transporting coal to six major power grids, five major power generation companies, more than 380 key power plants, ten major steel companies, more than 6,000 other enterprises, and urban and rural residents.

Finally, regarding the port, the upgrade of the Qinhuangdao Port coal terminals has enabled the Da–Qin Railway to gradually divert coal traffic from other branch lines. Figure 3 below illustrates the coal flow of the Da–Qin Railway, which operates under a rail–sea combined transport model. Its starting point connects to the coal-rich “Three Western Regions,” while its endpoint links to the Qinhuangdao coal port. Due to its superior geographical advantage, the Da–Qin Railway’s service coverage extends widely so that increasingly more coal shipments from other railways (e.g., Beijing–Datong and Beijing–Yuanping) are diverted to the Da–Qin line. A small portion of road transport, limited by lower capacity, has also gradually transitioned to the Da–Qin Railway for transportation efficiency.



Figure 3: Coal Flow on the Da–Qin Railway.

East China and South China provide a vast trade market for the Da–Qin Railway. In 2004 alone, coal shipments through Qinhuangdao port accounted for about 60% of the total coal transported by the Da–Qin Railway. With the renovation and upgrade of the Qinhuangdao coal terminals, coal transportation on the Da–Qin Railway has become more concentrated, further improving unloading efficiency. The Qinhuangdao Phase IV Coal Terminal was constructed as a supporting project for the Da–Qin Railway Phase II, and it passed national acceptance in 1997. It consists of two 35,000-tonne berths, one 100,000-tonne berth, and reserves one 25,000-tonne berth, with a designed throughput capacity of 30 million tonnes and a reserved capacity of 40 million tonnes.⁷⁴

Due to its world-leading fully automated coal loading and unloading lines and the largest dedicated coal yard globally, Qinhuangdao Phase IV Coal Terminal shoulders the coal supply for the southeastern coastal areas and foreign trade export tasks. The terminal was actually the largest maritime transfer hub for China's northern coal transported to the south, for the coal shipments from this terminal account for 60% of the total coal output from coastal ports nationwide. In addition, some coal shipments that originally went through Tangshan Port, limited by its capacity, were redirected to Qinhuangdao Port, and some railway branch lines began directly converging their coal transport into the Da–Qin Railway.

⁷⁴ Wu Chuanbao [武传宝], The Fourth Phase Project of Qinhuangdao Port Coal Terminal Passed National Acceptance. *Port Engineering Technology*, no. 1 (1998): 64. [秦皇岛港煤码头四期工程通过国家验收, 《港工技术》1]

In summary, the above analysis shows that it is feasible for the Da–Qin Railway to achieve an annual transport volume of 200 million tonnes. First, coal remains China’s primary energy source in the 21st century, and data forecasts indicate that coal demand will not decrease but increase. China’s energy consumption structure reveals that coal demand will not see significant short-term changes, and the uneven distribution of coal resources has resulted in a long-term pattern of northern coal transported to the south. Second, the coal supply for the Da–Qin Railway is backed by the entire “Three Western Regions,” which thus provide a long-term stable coal source. Third, judging from its coal flow structure, the Da–Qin Railway leverages Qinhuangdao Port to extend its reach to markets across East and South China. In response to the rapid economic development and increasing coal demand, the Da–Qin Railway must continue capacity expansion in order to fulfil its role as a major coal transport railway.

Key Technologies for Operating 20,000-Tonne Heavy-Haul Unit Trains

From 2003, the Da–Qin Railway underwent capacity expansion, and in 2004, its annual transport volume reached 150 million tonnes. To further alleviate the coal-electricity shortage, in 2005, the Ministry of Railways proposed a new goal for the Da–Qin Railway to achieve an annual transport capacity of 200 million tonnes, and an amount of 4.5 billion RMB was invested into the project of full-line capacity expansion and upgrading, covering signalling, communication, train operations, and rolling stock. Furthermore, in March 2005, under the unified planning by the Ministry of Railways, all railway sub-bureaus were abolished, and Taiyuan, Xi’an, and Wuhan Railway Bureaus were established. Along with the original fifteen railway bureaus, a total of eighteen railway bureaus directly managed stations and segments nationwide. To achieve the 200-million-tonne annual transport target, the Taiyuan Railway Bureau, in charge of the Da–Qin Railway, continuously optimised the railway line resources, increased the number of heavy-haul trains, improved transport efficiency, and reduced unloading time. As of December 25, 2005, the Da–Qin Railway had reached its annual transport volume goal of 200.18 million tonnes, surpassing the deadline by 6 days.

At that time, the International Heavy-Haul Association unanimously regarded 200 million tonnes as the theoretical limit for a single heavy-haul railway’s annual transport capacity. However, the Da–Qin Railway achieved this target in a relatively short time, creating a miracle of heavy-haul transport and marking China’s leap to global leadership in this field.

Operating 20,000-tonne heavy-haul trains is not only a realistic need for the Da–Qin Railway’s development but also a global trend. The weight of a heavy-haul train is not just a numerical increase; it must also be compatible with train speed and traffic

density. To achieve the target of transporting 200 million tonnes annually, the Da–Qin Railway must balance train weight, density, and speed. For instance, assuming the use of a C_{76} train car with an axle load of 25 tonnes, calculations show that if the train weight is 10,000 tonnes, seventy-two pairs of trains can run per day; if the train weight increases to 20,000 tonnes, only thirty pairs are allowed to run per day.

This indicates that, with a fixed transport volume, heavier trains mean lower traffic density, while lighter trains require higher density. Consequently, under a fixed axle load, choosing the optimal combination of train weight and density is a key issue in the 200-million-tonne expansion project.

In 2002, to reach an annual transport capacity of 100 million tonnes, Da–Qin trains operated at speeds up to 80 km/h, with a daily train density of up to eighty-seven pairs and individual train traction weight of 5,000–6,000 tonnes. According to the transport capacity formula, reducing train headway (the reciprocal of train density) from 14 min to 10 min can increase capacity by 40%; increasing train speed from 80 km/h to 120 km/h, despite various limiting factors, can increase capacity by 50%; increasing train's traction weight from 5,000 tonnes to 20,000 tonnes can triple transport capacity.⁷⁵ At the time, many countries with developed heavy-haul rail systems increased total train weight to boost freight capacity. For example, Australia operated 7,291-tonne trains in 1997, and South Africa and Brazil routinely ran 20,000-tonne trains. Increasing train weight (e.g., adopting heavy-haul trains) while reducing train density is the most efficient way to meet long-term coal transport demand without constructing new lines. Obviously, of equal importance is reducing train density, because when train density is high, longer extended track is needed. In practice, Da–Qin's 12,000-tonne and 15,000-tonne trains required longer extended tracks than 20,000-tonne trains.

Thus, to achieve the 200 million tonnes/year target by 2005 and the long-term goals of 300 million and 400 million tonnes, it is essential to increase the weight of heavy-haul trains, that is, 20,000-tonne trains.

The 21st century has seen a clear trend in railway development: high-speed passenger transport and heavy-haul freight transport. While the 20,000-tonne heavy-haul trains on the Da–Qin Railway fit this trend, boosting train weight from 5,000 tonnes to 20,000 tonnes presents major technical hurdles, with wireless locomotive control (e.g., Locotrol) being a decisive factor.

The first challenge to address is the synchronised operation of multiple locomotives. To increase the carrying capacity of heavy-haul trains, it is necessary to expand the train formation, often requiring more than a hundred cars. To haul such a long train, multiple locomotives are needed—for example, two coupled at the

⁷⁵ Geng Zhixiu [耿志修], *Heavy-Haul Transportation Technologies on the Datong–Qinhuangdao Railway* (China Railway Publishing House Co., Ltd., 2009), 11. [《大秦铁路重载运输技术》。中国铁道出版社]

front or one at the front and another in the middle. However, whether the locomotives are placed at the front for pulling or distributed along the train, if the coordination between them is inadequate, it could jeopardise the safe operation of the heavy-haul train. Therefore, achieving synchronised control between two or more locomotives is crucial for the safe operation of long, heavy trains.

The solution lies in locomotive synchronous control technology. It can be divided into wireless synchronous control technology and electronically controlled pneumatic (ECP) braking technology. Based on the suitability analysis for freight trains on the Da–Qin Railway and thorough technical–economic evaluations, wireless synchronous control technology was selected for Da–Qin’s 20,000 tonne heavy-haul trains.

The principle of wireless synchronous control technology is as follows. The lead locomotive is equipped with a master control unit, while trailing locomotives are fitted with slave control units. The lead locomotive sends commands via wireless communication, and the slave units receive and process these signals before executing them through control circuits—managing acceleration, braking, and other functions to ensure synchronous movement among all locomotives. Figure 4 below illustrates this technology: Locomotive #1 (the master) sends signals via wireless communication to Locomotives #2, #3, and #4 (the slaves), which respond accordingly.

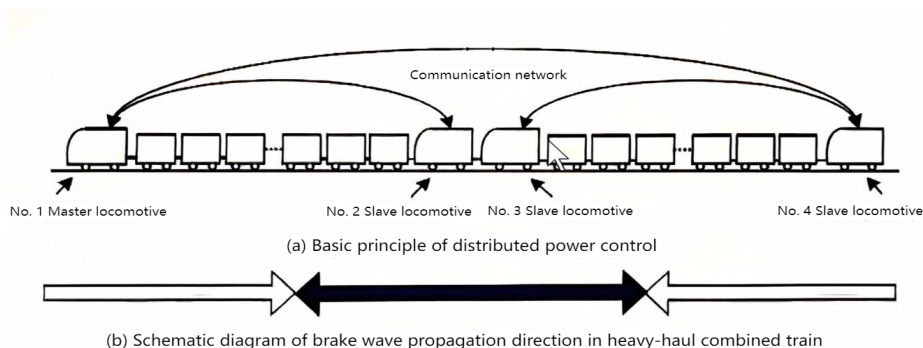


Figure 4: Schematic Diagram of Wireless Locomotive Operation (Locotrol System).

It is clear that the technology enables synchronous traction and braking across the entire train formation, achieving smoother locomotive control, reducing air filling/venting times, shortening braking distances, and ultimately minimising train longitudinal impacts while ensuring reliable re-braking performance.

Before this technology was used, as early as the 1960s, the United States adopted distributed power operation by placing one or more locomotives in the middle of a train. Initially, communication was maintained via whistle signals and later by wireless telephones. However, as train weights increased, this method could no

longer guarantee operational safety. In the 1980s and 1990s, with the development of computer technology, the United States began fully applying computerised systems to locomotive control.

On the early heavy-haul trains of the Da–Qin Railway, synchronised locomotive control technology was not used. As a result, a 10,000-tonne heavy-haul train composed of fifty-three cars once experienced excessive traction force, which led to the separation and coupler breakage of eleven cars. The Da–Qin line has fifty-two tunnels with a total length of 65.8 km, including the 8400-m-long Jundu Maintain Tunnel, and some sections feature steep gradients (see Figure 5), making heavy-haul trains prone to splitting or coupler failures during operation. If a 10,000-tonne train already had such problems, imagine the disastrous accident rate for a 20,000-tonne train hauling two hundred cars, which had no synchronised control and relied solely on manual driver coordination! Clearly, synchronised locomotive control is critical to operating 20,000-tonne heavy-haul trains on the Da–Qin Railway.

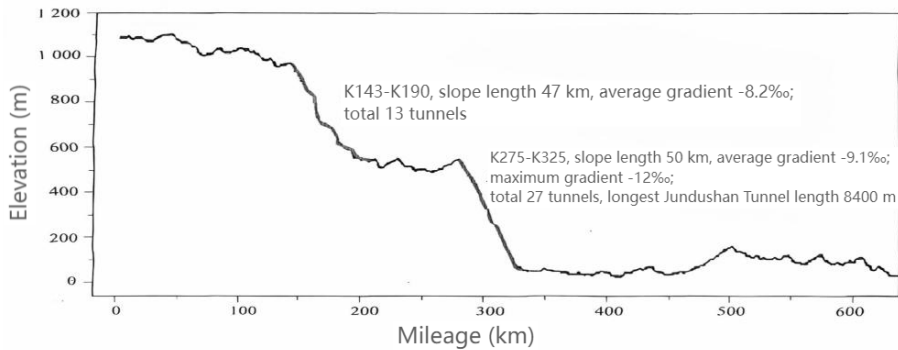


Figure 5: Schematic Diagram of the Da–Qin Railway Elevation Profile.

Source: Heavy-Haul Transportation Technology of the Da–Qin Railway.

Mastering this technology requires overcoming technical challenges in three aspects: communication, braking, and longitudinal train dynamics.

First, we discuss the requirements for communication signalling. Communication signals, as the name suggests, transmit commands and instructions. As mentioned earlier, the operation of 20,000-tonne heavy-haul trains relies on a wireless synchronous control system, where the lead locomotive transmits commands via wireless signals to slave locomotives. Any lack of synchronisation in locomotive operation would jeopardise safety, so precise coordination is critical. However, the Da–Qin Railway runs through numerous tunnels, which severely degrade wireless signal transmission. This necessitates a wireless data transmission system with high standards for efficiency, accuracy, and minimal error to ensure that commands from the lead locomotive reach all slave units accurately.

The United States had already begun testing wireless control systems for 10,000-tonne heavy-haul trains in the 1990s, and it had deployed several locomotives with this technology. However, foreign heavy-haul railways primarily operate on flat terrains, where train speeds and traffic density are lower than those on the Da–Qin Railway, reducing demands on data transmission quality. In contrast, the Da–Qin Railway traverses forty-three tunnels across low-altitude hilly terrain and thus imposes far stricter requirements for real-time and error-free signal transmission. This reality meant that China had to develop its own solutions and foreign technology could not be directly adopted.

To overcome wireless communication challenges in mountainous areas, the Da–Qin Railway innovatively integrated the Global System for Mobile Communications–Railway (GSM-R) with Locotrol technology, to ensure a transition from point-to-point signalling to network-based wireless transmission. This breakthrough resolved signal degradation caused by distance and terrain, establishing a uniquely Chinese heavy-haul wireless communication framework and laying the foundation for the successful operation of 20,000-tonne heavy-haul trains on the Da–Qin Railway.

Second, we consider the requirements for braking systems. All vehicles require braking systems to ensure the safety of drivers and passengers. These systems work by converting the kinetic energy of the vehicle into other forms of energy, thereby slowing or stopping it. Whether it's conventional rail, high-speed rail, or heavy-haul rail, braking systems are essential, but the requirements vary depending on the type of train. As train weight and speed increase, so do the demands on the braking system.

Train braking methods are divided into friction braking and dynamic braking, with the latter further categorised into rheostatic braking and regenerative braking. Heavy-haul electric locomotives typically use rheostatic braking, where the traction motors switch to generator mode, converting the wheels' kinetic energy into electricity, which is then dissipated as heat in resistor banks, thereby reducing speed.

For the Da–Qin Railway, trains with more than a hundred cars often operate on downslopes where dynamic braking alone is insufficient to control momentum. In such cases, drivers must supplement with air braking (pneumatic braking). The principle of air braking involves three stages: (1) charging (release): during normal operation, high-pressure air fills the brake pipe, releasing the brakes on each car and allowing free wheel rotation; (2) depressurisation (braking): when the driver activates the brake valve, air is released from the pipe, pressure drops, and brake shoes clamp the wheels via friction; (3) recharging (release again): when brakes are released, the pipe re-pressurises, pushing the brake shoes away to resume free rotation. The frequency of air braking depends on factors such as dynamic braking efficiency, gradient, and driver skill.

The Da–Qin Railway's uphill direction features long, steep gradients (e.g., a 50-km, 12‰ descent between Huashaoying and Chawu), thus requiring frequent braking. Longer trains mean longer recharge time—for instance, a 10,000-tonne train takes more than twice as long to recharge as a 5,000-tonne one. Tests show

that 10,000-tonne trains on the Da–Qin Railway require less than 4 min for air brake recharge. For a proposed 20,000-tonne train, recharge time would far exceed 4 min. As train length increases, compressed air transmission distance and recharge time rise, which can weaken braking effectiveness and cause braking asynchrony between cars, potentially risking coupler failures from excessive compression.

In general, the Da–Qin Railway faced two major difficulties when using traditional air braking systems. First, the extended downhill sections of the Da–Qin Railway required cyclic use of air braking, and once the train driver lost control of speed, it would pose a threat to operational safety. Second, the excessive length of heavy-haul train formations led to prolonged recharge time or insufficient recharging of the rear cars, resulting in compression between cars or inconsistent braking, which may cause operational accidents. Therefore, due to issues such as excessive braking distance, inconsistent braking between cars, and mismatches between air braking and electric braking, traditional air braking systems cannot meet the demands of long heavy-haul trains with large formations and massive weights.

Historically, when the traction weight of heavy-haul trains exceeds 15,000 tonnes, the use of air braking technology becomes prone to coupler breakage and derailment accidents. For example, in the United States, coupler separation accidents accounted for about 70% of the country's railway accidents. Therefore, in the 1990s, to overcome the shortcomings of air braking technology and achieve synchronous braking operations for long heavy-haul trains, the United States developed electronically controlled pneumatic (ECP) braking technology using microcomputers to enhance the air braking system. ECP can shorten braking distances, reduce longitudinal forces, and improve the operational performance of heavy-haul trains. The technology has since been adopted in countries such as Canada, Australia, and South Africa. By 2005, more than 10,000 heavy-haul trains had been equipped with ECP, which achieved certain economic benefits.

ECP braking adds electrical control components to the traditional air braking system. During braking, the locomotive issues braking commands via the ECP communication device, and each car's control unit performs charging operations upon receiving the command. During the release phase, the control unit dynamically adjusts the braking pressure by modulating the proportional valve's opening based on the real-time control signal. This enables graduated pressure reduction for precise speed control and smoother brake release.

In 2003, Southwest Jiaotong University and the Sifang Rolling Stock Plant concluded that the existing 120-type air brake systems used on the Da–Qin Railway trains could not meet the demands of 20,000-tonne heavy-haul transportation. They recommended the adoption of ECP technology and proposed a detailed design plan. In July, a “Symposium on Capacity Expansion Strategies for the Da–Qin Railway” was held in Datong by the Beijing Railway Society, the Tianjin Railway Society, and the Heavy-Haul Committee of Chinese Railway Society. During the conference, experts and scholars discussed the 200-million-tonne capacity target for the Da–Qin Railway

and proposed that “ECP technology should be introduced and promoted on the Da–Qin Railway to achieve synchronised braking, gradual release, and recharging across the entire train, which will mark a significant transformation in China’s traditional braking systems.”⁷⁶

Third is the issue of requirements for mitigating longitudinal train forces. In heavy-haul operations, factors such as track conditions and train performance create varying forces between locomotives and wagons. Excessive coupler forces—whether in tension (exceeding coupler strength during deceleration/brake release) or compression (during buffering)—can lead to coupler breakage, train separation, or even derailments. The dynamics of heavy-haul trains form a complex system, where excessive longitudinal forces critically compromise safety. Thus, coupler strength and force management are key challenges in longitudinal dynamics and essential technologies for operating 20,000-tonne heavy-haul trains on the Da–Qin Railway.

According to the principles of train longitudinal dynamics, the coupler tension generated during braking is proportional to the number of vehicles in the train. Consequently, the coupler forces in heavy-haul trains far exceed those in conventional freight trains. Under identical operational conditions—including track infrastructure, technical equipment, and driving techniques—a 10,000-tonne heavy-haul train on the Da–Qin Railway generates longitudinal forces roughly twice those of a 5,000-tonne train, while a 20,000-tonne train produces approximately four times the forces of a 5,000-tonne train.

In November 2004, the Ministry of Railways conducted experimental tests of Locotrol distributed power technology on the Da–Qin Railway. After nearly 1 month of trials, it was found that the significant coupler forces observed in the middle sections of 20,000-tonne trains were primarily caused by air braking. Two key solutions were proposed: one, adopting ECP technology to enhance braking performance; two, utilising locomotives with stronger dynamic braking capacity to reduce reliance on air braking.⁷⁷ They are in line with international experience in heavy-haul operations, which indicates that when train weights exceed 15,000 tonnes, relying solely on conventional single-consist air braking systems risks coupler fractures and derailments. Thus, to operate 20,000-tonne trains safely on the Da–Qin Railway, distributed power and synchronised braking technologies are essential.

To address braking challenges on long steep gradients, the Da–Qin Railway finally implemented locomotive remote control technology (e.g., Locotrol), Grade E

⁷⁶ Zhang Guosheng and Zhou Xiaohua [张国胜, 周小华], Discussion on the Expansion of the Datong–Qinhuangdao Railway Capacity to 200 Million Tonnes. *Railway Knowledge*, no. 5 (2003): 14–15. [大秦铁路扩能至两亿吨的研讨, 《铁道知识》5]

⁷⁷ Yang Wankun, Lu Yang, Zhang Bo and Li Jiebo [杨万坤, 陆阳, 张波, 李杰波], Test and Analysis of Longitudinal Force in the Middle of 20,000-tonne Train Formation on the Da–Qin Railway. *Proceedings of the 2005 Railway Traction Power Academic Annual Conference* (2005): 4. [大秦线2万吨组合列车中部纵向力测试分析, 《2005年铁道牵引动力学术年会论文集》]

steel couplers, and automatic decoupling safeguards. Moreover, to meet the demands of wireless communication distance and quality, GSM-R technology was innovatively integrated into the wireless locomotive control system. To further enhance transport capacity, 10,000-tonne unit trains were introduced to achieve integrated loading, unloading, and transportation logistics.

The Da-Qin Railway's 200-million-tonne capacity expansion is a vast and complex project that involves many aspects. The Ministry of Railways put forward a "demand-driven, engineering-based, system-integrated, and all-encompassing" strategy to lead technological innovation and coordinated development for the capacity expansion of the heavy-haul system.

Locomotive Technology

Locomotive is the power source for a heavy-haul train. In 1985, China independently developed the eight-axle heavy-haul freight SS₄ electric locomotive, which adopted Alternating Current–Direct Current (AC–DC) transmission and featured an internal multiple-unit function. This design enabled multiple locomotives to operate in combined traction and significantly increased the hauling capacity of heavy freight trains. To haul 10,000-tonne trains, the Da-Qin Railway had used two improved SS₄ locomotives in an external multiple-unit configuration. However, to haul 20,000-tonne trains, which doubles the load, the traditional configuration of two SS₄ became inadequate due to the technical challenges of external multiple-unit configuration.

In 2004, led by the Beijing Railway Bureau, a feasibility test was carried out for 20,000-tonne heavy-haul train operations. The test train consisted of four SS₄ locomotives equipped with Locotrol technology and 204 C₈₀ open-top train cars. The route ran from Libazhuang Village along the Datong–Taiyuan Railway to Liucun South Station in Qinhuangdao City. The test results confirmed that four SS₄ locomotives equipped with Locotrol could successfully haul a 20,000-tonne heavy-haul train.

While Locotrol was adopted by most heavy-haul countries to operate 5,000-tonne trains, China's 20,000-tonne train operation represents a major technological leap, for it expands the application scope of Locotrol and opens a new chapter in global heavy-haul railway history. In October 2004, multiple tests were conducted on the SS₄ electric locomotive, and all performance metrics met operational requirements. In March 2006, the Da-Qin Railway officially began operating one pair of 20,000-tonne heavy-haul combined trains. In June, the number increased to more than four pairs, and in July, more than fifteen pairs were in operation. Furthermore, under the coordination of the Ministry of Railways, the H_DX1 locomotive was developed jointly by Zhuzhou Electric Locomotive Works in collaboration with its German partner. This imported and adapted locomotive could haul long, heavy trains at speeds of 120 km/h, which meets the demands of long steep gradients on the Da-Qin Railway.

Freight Car Technology

Freight car is the body of the Da–Qin heavy-haul system. By coupling many freight cars together, large-scale freight transport is achieved. To meet the demands of coal transport and reduce costs, heavy-haul countries around the world all attach great importance to the development and deployment of coal cars. Globally, there are two main types of coal transport vehicles: (1) specialised open-top coal train cars and hoppers widely adopted in countries like the United States; and (2) self-unloading open-top train cars used in Germany, which are generally smaller in volume and capacity. In the 1980s, China developed its first generation of C_{63} train cars equipped with rotating couplers, buffers, and braking devices. These were later improved to the C_{63A} type to meet the Da–Qin Railway’s coal transport needs. With the increasing demand for freight transportation, the body structure of open-top coal train cars has evolved from the single-hopper trough design to the double-hopper trough design. To further advance heavy-haul transportation technology, China collaborated with the United States in 1997 to develop and introduce aluminium alloy double-hopper train cars, which were deployed on the Da–Qin Railway. These cars not only increased the capacity of coal transportation but also reduced their own weight and lowered the centre of gravity, thereby enhancing their load-bearing capacity.

In 2002, the Ministry of Railways proposed a strategy for leapfrog development in the railway sector, requiring the Da–Qin Railway to achieve an annual transport volume of 100 million tonnes, 200 million tonnes, or even 250 million tonnes. In 2003, the Da–Qin Railway Transport Capacity Expansion Technology Symposium defined the cargo types and operational standards for rolling stock. At that time, the main types of rolling stock in use on the Da–Qin Railway included C_{63A} , C_{76} , C_{80} , C_{61Y} , C_{64} , and C_{62} . Among these, the C_{63A} , C_{76} , and C_{80} models could meet the marshalling requirements for 10,000-tonne trains. However, to operate 20,000-tonne heavy-haul trains, further upgrades to the existing rolling stock were necessary.

To achieve the leapfrog development of the Da–Qin Railway, Qiqihar Rolling Stock Plant once again took the initiative to undertake the R&D of new open-top coal train cars. Through continuous technology introduction, absorption, and re-innovation and by adhering to the principles of “advanced, mature, reliable, economical, and practical,” the Qiqihar Rolling Stock Plant in 2004 successfully developed the C_{80} aluminium alloy and C_{80B} stainless steel freight cars, which became the primary coal transportation vehicles for the Da–Qin Railway’s heavy-haul operations.

These two new train cars were upgraded based on the C_{63A} model, and increased the vehicle load capacity from 61 tonnes to 80 tonnes—a 31.3% improvement. The tractive weight was raised from 10,000 tonnes to 20,000 tonnes. These enhancements not only met the marshalling requirements of the two hundred-car formations on the Da–Qin Railway but also complied with the no-uncoupling continuous unloading operations of Qinhuangdao’s triple-car rotary dumpers. This provided the essential

technical equipment for the Da-Qin Railway to achieve annual coal transport volume of 150 million tonnes in 2004, 200 million tonnes in 2005, and 250 million tonnes in 2006.

The C₈₀ aluminium alloy and C_{80B} stainless steel open-top coal train cars filled multiple gaps in China's heavy-haul transportation sector. For instance, they resolved technical challenges in fatigue strength design for stainless steel car bodies, overcame lightweight structural engineering difficulties, and provided new evaluation standards for longitudinal dynamics in China's heavy-haul freight cars.

The evaluation of technological innovation success is not determined solely by test data but must be proven by practical results. In 2004, the Taiyuan Railway Bureau increased the formation of C₈₀ and C₇₆ trains from 102 cars to 105 cars, adding 240 tonnes of cargo per train car. In 2006, to further increase coal transport volume on the Da-Qin Railway, the train departure interval was shortened from 16 min to 13 min. The innovative achievements in open-top coal train cars significantly alleviate China's coal transport bottlenecks and provide a reliable power supply for the country's steady and healthy economic development.

Communication and Signalling

The Da-Qin Railway passes through a region where 60% of the terrain consists of mountains and hills, with complex geological structures. Long steep gradients, tunnel clusters, and canyon landscapes pose significant challenges to wireless communications along the railway line. Traditional communication methods have limitations in data transmission quality, significantly affecting the use of wireless train control technologies (e.g., Locotrol) for train formations and station operations. In 2003, China upgraded the communication network on the Da-Qin Railway by using 400 MHz +400 kHz wireless systems to operate two 5,000-tonne trains. However, this communication method, susceptible to interference from electrification, would result in extremely poor signal quality when trains traverse mountainous areas and tunnels. Consequently, it fails to meet the requirements of operating 20,000-tonne heavy-haul trains on the Da-Qin Railway, and an expansion and upgrade of existing communication equipment is imperative. To resolve the issue of weak communication signals in mountainous areas, the Da-Qin Railway pioneered the integration of Locotrol technology with the GSM-R system.

Compared to the 450 MHz digital radio system, GSM-R offers several advantages: it is unaffected by communication distance or train formation size; and it significantly improves safety for trains in tunnels and mountainous terrain. The Da-Qin Railway became the first line in China that (i) adopted GSM-R communication technology in operation and (ii) independently developed new devices such as application nodes and on-board communication units. This innovation successfully solved the problem of synchronised wireless locomotive control and provided crucial technical support

for operating 20,000-tonne trains. Subsequently, the Ministry of Railways planned to use GSM-R as the standard communication system for all newly built railway lines in China.

Track and Bridge Infrastructure

Tracks and bridges are essential infrastructure for railway operations, and their quality directly determines whether trains can run smoothly. It is well known that the heavier the train, the greater the pressure and damage imposed on the subgrade. The existing infrastructure cannot meet the operational demands of running 20,000-tonne heavy-haul trains on the Da–Qin Railway.

Originally, the subgrade of the Da–Qin Railway was designed for conventional lines, with bridges built for medium loading capacity. However, as traffic volume and axle load increased, infrastructure damage escalated significantly. After trial operations of 10,000-tonne freight trains in 2004, the following issues emerged: rail damage increased by 50%-80% year-on-year; damage rates of seamless tracks reached 224%; severe track instability was observed, particularly on curved sections; heavy roadbed contamination and frequent mud-pumping occurred; bridge safety margins decreased after axle loads increased to 25 tonnes.

To achieve an annual freight volume of 200 million tonnes and enable 20,000-tonne heavy-haul operations, it is imperative to enhance the strength and rigidity of the existing tracks and bridges, adopt heavy-haul rails to extend their service life, and improve the quality of subgrade while reinforcing the bearing capacity of the ballast. These measures are essential to ensuring safe and stable heavy-haul operations and make it possible to unlock the Da–Qin Railway's full transport potential.

The following critical upgrades were carried out:

- Replacing standard rails (e.g., 75 kg/m) with heavy-haul rails (25,773 rails replaced);
- Conducting periodic inspections and strength tests on bridges and culverts, with immediate replacements for non-compliant structures;
- Improving subgrade quality and increasing thickness and width of the ballast to enhance load-bearing capacity and track stability; and
- Optimising track maintenance during scheduled “maintenance windows” (e.g., overnight or low-traffic periods).

Operational Efficiency

The 200-million-tonne capacity expansion project was carried out while the normal operation of the Da–Qin Railway was ensured. Consequently, beyond engineering challenges, the most critical aspect was to resolve the conflict between train operations

and construction. This required scientific planning and unified coordination to further improve operational efficiency. To minimise disruptions, construction was conducted during “maintenance windows” (short scheduled downtime). Once the window closed, all 3,000-odd workers immediately cleared the tracks, allowing the line to resume service. Reflecting on the project, a deputy director of the Datong Railway Bureau remarked, “Such a large-scale, multi-team, and spatially overlapping upgrade of an active rail line is exceedingly rare in China’s railway history.”⁷⁸

To achieve the annual 200-million-tonne target, the Datong Railway Bureau adopted the strategy of making trains longer, running more trains, and making trains faster. A total of 258 measures were implemented and twenty-one regulations were revised.

(1) Making trains longer—increasing train length to raise loading capacity. As China’s first dedicated heavy-haul railway, the Da–Qin Railway increased payload capacity primarily by expanding train formations. Another feasible strategy was to increase axle loads.

The Da–Qin Railway raised daily train pairs from 2.6 in 2003 to 31.5, while train formation length grew from 102 to 105 cars. Simultaneously, axle loads were upgraded. Internationally, since the 1990s, heavy-haul nations like the United States (phasing out 25-tonne axles for 33-tonne ones), Canada (33-tonne), and Australia (35-tonne)—followed by India, Russia, and South Africa—adopted higher axle loads to reduce costs. Due to technical constraints, China delayed adopting 23-tonne and 25-tonne axles broadly, but it was on the Da–Qin Railway that C_{76A} train cars with 25-tonne axles were deployed, and later, axle loads were further increased while tare weight was reduced.

(2) Running more trains—appropriately increasing the railway’s train density. To enhance train density along the entire Da–Qin Railway, measures were taken to reduce inspection time, speed up unloading turnover, and continuously optimise the operating routes, thereby improving transport efficiency. To ensure smooth operations during construction, train operation plans were successively developed with eighty, eighty-three, and eighty-five train pairs per day during construction periods, as well as 90, 96, and 102 train pairs per day during construction intervals.⁷⁹ These efforts maintained the Da–Qin Railway’s average daily shipment volume at 520,000 tonnes even amid construction work.

⁷⁸ Wang Zheng [王政], The Datong–Qinghuangdao Railway: Building the World’s First-Class Heavy-Haul Railway, *People’s Daily*, September 10, 2005 (001). [大秦线：打造世界一流重载铁路，《人民日报》].

⁷⁹ Li Qiang and Liang Chenggu [李强，梁成谷], Persist in Expanding Domestic Reproduction to Ensure Stable Operation of the National Economy: Record of the Capacity Expansion and Upgrade Project of the Datong–Qinghuangdao Railway. *China Railway*, no. 10 (2005): 28–30. [坚持内涵扩大再生产确保国民经济平稳运行——记大秦铁路扩能改造工程，《中国铁路》10]

(3) Making trains faster—improving the railway’s operating speed. To achieve this, the railway authorities optimised operations by establishing direct routes between coal loading sites and ports so that transit time decreased. As a result, freight volume in 2005 surged by 25% compared to previous years. Given the Da-Qin Railway’s challenging terrain through mountains and complex rail conditions, upgrades were made to enhance the quality of track, signalling, and other critical infrastructure. Besides, to minimise conflicts between construction and train operations, the rolling stock department eliminated speed restrictions for heavy-haul (10,000-tonne) trains in certain sections and replaced station stops with section stops. Through initiatives like the “Transport Boost Campaign” and “Fault Reduction Drive,” equipment failures were minimised, and operational efficiency was significantly improved.

Transportation Management for Freight Volume Increase

The Da-Qin Railway has a stable and sufficient supply of coal and fixed transportation direction, that is, transporting coal from Shanxi, western Inner Mongolia, and northern Shaanxi to Qinhuangdao Port and its surrounding areas. For these reasons, the Railway has a unique transportation management model, a closed-loop heavy-haul operation involving full-train loading, transportation, unloading, and empty return.

There are several differences between the Da-Qin Railway and its international peers. First, the Da-Qin Railway is a high-density, high-weight railway that needs to coordinate with other railway branches. Lines such as Datong-Taiyuan, Datong Hub, and Datong-Zhunge’er channel the obtained coal into the Da-Qin Railway. Second, coal is categorised into different types according to its different uses, which makes it impossible for the Da-Qin Railway to adopt the unit-train cyclic loading model used in foreign heavy-haul systems. Furthermore, while transporting coal, the Da-Qin Railway must also take passenger transport into account.

It is on the basis of its heavy-haul operation model with Chinese characteristics that the Da-Qin Railway continues to break records in coal transportation volume, significantly alleviating the coal supply tension in China’s central and eastern regions. Now, to operate 20,000-tonne heavy-haul trains and haul an annual volume of 200 million tonnes, the Da-Qin Railway must also further optimise its transportation management by designing a rational, scientific, and systematic plan.

However, the upgrade of Da-Qin’s closed-loop heavy-haul operation model faces many challenges. The Da-Qin Railway is one of the few railways in the world with high traffic density and massive transport volume. The technical standards of branch railways are not consistent, and the origins and destinations of coal flows are complex. The growing transport volume and continual upgrades to infrastructure

have led to complex connectivity issues, which indirectly affect the railway's operational safety. The Da-Qin Railway operates under an integrated transport organisation framework. Consequently, during its upgrade and modernisation, the four key stages—loading management, train operation, unloading management, and empty car repositioning—cannot be optimised in isolation. Instead, a holistic approach must be taken, integrating loading, line operations, and unloading zones into a unified system. In other words, the capacity expansion project for the Da-Qin Railway's 20,000-tonne trains requires comprehensive consideration of operational challenges across all transport segments—loading, transit, and unloading—to design an optimal transport structure.

Specifically, it is essential to rationally plan the weight, speed, and density of trains on the Da-Qin Railway. According to railway freight theory, there are three primary methods to enhance transport capacity: (1) increasing axle load and operating long, heavy-haul train formations; (2) reducing the length of restricted sections, tracking intervals, and station clearance time to boost train density; and (3) simultaneously increasing train weight and density. Regardless of the approach chosen, train weight, speed, and density are interdependent constraints. With a fixed traction capacity, increasing the weight leads to reduced speed and density. Conversely, with a set train weight, higher speeds can shorten travel time, enabling greater density. Therefore, selecting the optimal “weight–speed–density” combination is critical to maximising transport capacity and achieving the Da-Qin Railway's annual target of 200 million tonnes.

First, operating 20,000-tonne heavy-haul trains is the optimal choice for the Da-Qin Railway. Increasing train weight is a common strategy among heavy-haul railways worldwide, and the Da-Qin Railway must similarly focus on weight to meet its annual target. However, as mentioned earlier, factors like train density and gradient limit endless increases in weight, making the selection of an appropriate weight crucial. The figure below (Figure 6) illustrates the relationship between train traction weight and transport capacity. As traction weight rises—from 10,000 tonnes to 20,000 tonnes—transport capacity increases by 56%. Beyond this, the gains diminish: moving from 50,000 tonnes to 60,000 tonnes yields only a 5.8% improvement. Moreover, excessive weight escalates track maintenance costs and extends “maintenance windows,” suggesting minimal returns for capacities beyond 20,000 tonnes. Additionally, steep gradients along the Da-Qin Railway impose a hard limit: traction weight cannot exceed 20,000 tonnes; otherwise, it will affect train braking and may lead to operational accidents.

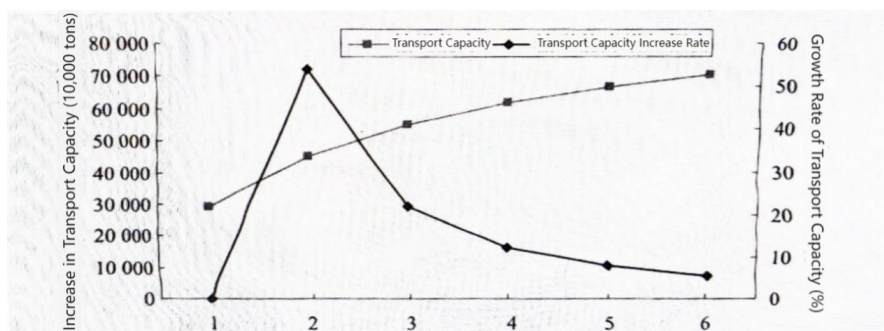


Figure 6: Relationship Between Traction Weight and Railway Transport Capacity.

Source: Heavy-Haul Transport Technology of the Da-Qin Railway.

To increase its transport capacity, the Da-Qin Railway cannot rely solely on increasing the train weight. Excessively heavy trains lead to correspondingly higher investment and renovation costs for the line, but such high investment does not proportionally translate into increased transport capacity. Therefore, based on China's actual railway transportation conditions, operating 20,000-tonne heavy-haul trains is the most reasonable choice. Furthermore, to support the operation of 20,000-tonne heavy-haul combined trains on the line, it is necessary to use four SS_{4G} electric locomotives and two HX high-power locomotives, in addition to using Locotrol and related heavy-haul transport technologies. This configuration allows trains to reach a maximum speed of 80 km/h, with an average speed of 65 km/h on gradient-restricted sections. Due to limitations on certain long and steep gradients, some trains must operate at 10,000 tonnes. Hence, the traction strategy for the Da-Qin Railway should prioritise 20,000-tonne trains while supplementing with 10,000-tonne trains.

Secondly, to increase the train density on the Da-Qin Railway, it is crucial to address the restrictions posed by train tracking time (the minimum time separation between consecutive trains on the same track or route) on long steep gradients and the departure intervals at Hudong Station. The maximum speed of 10,000-tonne heavy-haul trains on long steep gradients does not exceed 70 km/h, with an average speed of 46.4 km/h, which results in a minimum train tracking interval of no less than 9 min. If the Da-Qin Railway introduces new models such as C₈₀ freight cars and HX locomotives and raises the speed from 40 km/h to 50 km/h, the minimum train tracking time still remains 9–10 min. Even with the use of Locotrol technology for 20,000-tonne heavy-haul trains, which shortens braking distances, the tracking time interval does not exceed 11 min, meaning that train speeds on the Da-Qin Railway cannot be too high. For Hudong Station, the lateral turnout speed in its throat area must be strictly controlled, which significantly limits train departure efficiency, so capacity expansion project of the Station must be implemented based on the Da-Qin Railway's whole transportation organisation plan.

Next, let's discuss the upgrades of the Da-Qin Railway's transportation organisation from the following aspects.

In terms of loading management, the loading areas of the Da-Qin Railway are divided into three parts: stations, connecting lines, and Hudong Station, each with different requirements.

The loading station primarily serves to connect the traction capacities of various railway branch lines, requiring the selection of appropriate loading points for 5,000-tonne, 10,000-tonne, and 20,000-tonne trains based on actual conditions. On the Da-Qin Railway, the organisation of 20,000-tonne train marshalling stations can be arranged at Hudong and Yungang Stations. To achieve an annual transport volume of 200 million tonnes, it is necessary to upgrade the lines that meet the operating conditions. The Da-Qin Railway was originally designed with fifteen loading stations for 10,000-tonne trains, but in practice, only ten stations can load trains on the same day, which significantly restricted the railway's transportation capacity. The primary task of Hudong Station is to handle the arrival, departure, marshalling, and transfer operations of 10,000-tonne trains. Given that the train formation, departure track length, and equipment testing and adjustment for 10,000-tonne trains differ from those of branch lines, corresponding upgrades must also be made on Hudong Station.

The tracks of the loading areas must have connecting and throughput capacity to integrate with the loading point tracks and coordinate with lines experiencing limited throughput. Additionally, when Hudong Station's capacity proves insufficient, departmental coordination must be implemented to ensure smooth operations. Through rational allocation and unified planning, if a marshalling yard cannot support 20,000-tonne train operations, direct 5,000-tonne or 10,000-tonne trains can be despatched, with vehicle inspections at their respective stations before direct larger trains are reorganised at Hudong Station.

In terms of loading management, the unloading area is also divided into three parts: connecting lines, receiving stations, and ports. To some extent, unloading efficiency determines the capacity of the Da-Qin Railway. Coal is primarily transported by the Da-Qin Railway to such ports as Qinhuangdao, Tianjin, and Tangshan for unloading, then it is shipped by sea to other regions. Qinhuangdao Port, a coal export port supporting the Da-Qin Railway, possesses China's most advanced automated coal unloading equipment, and its Phase IV and V Coal Terminal expansion projects added sixty-five dedicated coal berths, increasing the port's coal handling capacity to 187 million tonnes annually. In 2005, the port's total throughput reached 169 million tonnes, of which 139.05 million tonnes were coal transported and unloaded via the Da-Qin Railway, accounting for 68.5% of the Railway's annual coal transport volume. This highlights the close cooperation and efficient linkage between the Da-Qin Railway and Qinhuangdao Port in coal transportation.

In terms of train operation organisation, the organisational processes on the Da-Qin Railway can be divided into collection and distribution. Collection refers to consolidating scattered cargo from multiple branch lines or loading points

into mainline and direct trains (e.g., the Da–Qin Railway). Distribution involves distributing bulk cargo transported via the mainlines to end users or further transport networks.

The existing carrying capacity of the Da–Qin Railway and some branch lines makes possible the capacity expansion project. For instance, from Hanjialing to Hudong Station, trains with hauling capacities ranging from 5000 tonnes to 10000 tonnes can operate, and direct, high-volume freight trains can be formed. Yungang branch line, as a loading line in the Datong Hub, supports trains with hauling capacities of 6,000–10,000 tonnes and is well-equipped to despatch direct trains to Hudong Station. Datong–Zhunge’er Railway, primarily tasked with local coal transport, can operate 10,000-tonne heavy-haul trains after capacity upgrades. Kouquan branch line, originally handling coal flows from the former Beijing–Datong Railway, could be upgraded to support 10,000-tonne trains. Other branches, such as the Datong–Baotou Railway, are also candidates for further capacity expansion.

To achieve an annual transport volume of 200 million tonnes, a coordinated transportation plan is devised for key routes as follows:

The route of Daxin (via the Datong–Taiyuan Railway) to Hanjialing to Hudong Section operates thirty-eight pairs of 10,000-tonne heavy-haul trains and twenty-three pairs of 5,000-tonne trains, reaching an annual volume of 118.1 million tonnes;

The route of Yungang branch line to Hudong Station runs eleven pairs of 10,000-tonne trains, achieving an annual volume of 34.9 million tonnes;

The route of the Datong–Zhunge’er Railway, to the Beijing–Baotou Railway, to Hudong Station, operates eight pairs of 10,000-tonne trains, with an annual volume of 24.1 million tonnes;

The route of Kouquan to Hanjialing to Hudong Section operates six pairs of 10,000-tonne trains, contributing 23.7 million tonnes annually;

The route of the Beijing–Baotou Railway, to Datong West, to Hudong Station, handles conventional freight trains, transporting 4.2 million tonnes of cargo per year.

The train flow organisation plan above clearly demonstrates Hudong Station’s pivotal role in marshalling trains for the Da–Qin Railway. It also reveals that operating 5,000-tonne trains on connecting lines within the loading zones can temporarily meet the Da–Qin’s 200-million-tonne annual transport target. However, expanding to 250 million, 300 million, or even 400 million tonnes would push the capacity limits of both the connecting lines and Hudong Station. To further enhance the Da–Qin Railway’s transport capacity, existing lines should maximise the operation of 20,000-tonne heavy-haul trains, concentrating freight flows to bypass Hudong Station with direct trains.

The distribution freight flow network of the Da–Qin Railway mainly includes eastern unloading zones, power plants along the Railway, the Beijing–Qinhuangdao Railway, the Beijing Railway Hub, and outbound customs railway lines (e.g., for international transit).