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SUPERENGINEERING

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Innovation evolution of China's high-speed rail industry

1 General engineering situation

As an exemplary industry that represents the transformation and upgrading of China's manufacturing industries, the high-speed rail industry has advanced and surpassed developed countries all over the world. This achievement resulted from the introduction, absorption, and indigenous innovation on the leveraging of core technologies and relevant engineering innovation systems. Moreover, China's high-speed rail industry has become a great name card on China's high-end equipment "going-out." Taking the statistical data of 2015, China's total railway length has reached 121000 km, and the operating length of the high-speed rail has reached 19000 km, covering more than 60% of the total length of the world's high-speed railways and 16% of the total railway length of the country. In addition, the performance of China's high-speed rail is leading the world standard among diverse dimensions (Table 1).

2 Landscape of high-speed rail industry's evolution

China's high-speed rail industry has experienced longitudinal evolution. Table 2 summarizes the key events that present the evolution of high-speed rail development.

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3 Major innovations of China's high-speed rail

3.1 High-speed train: From introduction and absorption to indigenous innovations

The Ministry of Railways began the introduction, absorption, and re-innovation strategy for the development of China's high-speed rail industry. In addition, they made the strategic principal on "introduce the advanced technologies, joint design and production, and build the indigenous high-speed rail brand the of China." Thereafter, with the coordination of the Ministry of Railways, CSR and CNR played as the two major actors that promote collaborations with four global partners on joint innovation of high-speed trains.

After two rounds of introduction of global high-speed train, the Ministry of Railways started to support the indigenous innovation of high-speed trains. Focusing on the CRH380 indigenous innovation goals, the central government issued science and technology research projects that embrace all the key players among the domestic high-speed rail industry, involving 25 universities, 11 research institutions, 51 national laboratories, 68 academicians, and more than 700 professors[1]. The first indigenous EMU CRH380 at 350 km/h speed level finally came into operations in 2010 (Fig. 1[2]), with the 9 core technologies (e.g., EMU system assembly, car body, bogie, traction transformer, main converter, traction motor, traction drive control system, train control network system, and brake system) and 10 complementary technologies (e.g., air-conditioning system, toilet, door, window, windshield, hooking device, flow receiving device, auxiliary power supply system, interior decoration materials, and seats) fully innovated indigenously.

1) Gao B, Li G, Zhen Z. High-speed Rail: An Analysis of the Chinese Innovation System. Beijing: Social Sciences Academic Press (in Chinese), 2016.
2) The figure is from Baidu Figures.

Table 1 Representative aspects of the world’s best performance of China’s high-speed rail industry

Representative aspects	Descriptions
Longest operating mileage	The operating length of the high-speed rail has reached 22000 km at the end of 2017, covering more than the sum of other countries all over the world.
Fastest engineering construction	China’s high-speed rail began to promote the introduction, absorption, and re-innovation development of road. Only 10 years later, the construction of “four vertical and four horizontal” railway network was completed.
Highest operating speed of high-speed train	486.1 km/h
Highest test speed of wheeling rail	605 km/h
Highest standard	In June 2011, Beijing–Shanghai high-speed railway was completed and became the world’s high-speed railway with the highest standard.
World’s first new high-speed railway operating in Alpine area	On December 1, 2012, the world’s first new high-speed railway operating in Alpine area, “Harbin–Dalian,” high-speed railway opened for operation.
World’s longest high-speed railway	On December 26, 2014, “Beijing–Guangzhou” high-speed railway, which was the world’s longest high-speed railway (2298 km in total), opened for operation.
Most complete electric multiple unit (EMU) pedigree	China owes EMUs with all speed levels ranging from 200 km/h to 500 km/h
World’s largest transport scale	By September 2017, more than 7 billion people have experienced high-speed rail transportation.

Sources: Summarized by http://www.xinhuanet.com/2015-01/25/c_1114122302.htm; http://baijiahao.baidu.com/s?id = 1587937602717839947&wfr = spider&for =

Table 2 Evolution of China’s high-speed rail industry

Development stage	**Representative events**
Before 2004	#The development of high-speed rail industry mainly relied on indigenous R&D. #Developed representative high-speed trains, such as “Blue Arrows,” “Chun Cheng,” “White Sharks,” and “China Star.” #The first indigenous high-speed railway: “Qing-Shen” special passenger line. #Speed leveraging on existing railway network.
2004–2008	#In January 2004, the State Council executive meeting adopted the “Medium- and Long-term Railway Network Planning” and started the “Four Vertical and Four Horizontal” railway network planning. #The Ministry of Railways created a strategy for the development of China’s high-speed rail industry: Introduce the advanced technologies, joint design and production and building the indigenous high-speed rail brands of China. #Promoted two-round global EMUs’ procurement tender with 200 km/h and 300 km/h speed levels. #Designed the oligopoly competition of high-speed rail industry between China South Railway (CSR) and China North Railway (CNR).
2008–2014	#Started the indigenous innovation development of high-speed rail after the release of “The Indigenous Innovation Joint Action Plan of China High-speed Train” in February 2008. #Targeted on the indigenous innovation of 350 km/h high-speed train. #Completed the indigenous innovation high-speed train of CRH380.
2015–Present	#Completed the merging of CSR and CNR into China Railway Rolling Corporation (CRRC), which determined its global competitive advantage. #Promoted the “going-out” strategy of China’s high-end equipment manufacturing industry and executed “One Belt One Road” initiatives. #Issued the medium- and long-term railway planning, namely, “eight vertical and eight horizontal” railway network planning.

Source: Chen J, Mei L, and Zhao C. The Mystery of the Breakthrough of High-speed Rail’s Core Technological Capabilities—Evolution of CRRC’s “Core” Strategy. Tsinghua Management Review, 2018(6).

3.2 Engineering construction of high-speed railway

To trigger the development and success of China’s high-speed rail industry, the central government promotes the domestic construction of high-speed railway network. The start of the country’s railway network construction, which approved “Medium- and Long-Term Railway Network Planning,” was in early 2004; the construction targeted building high-speed passenger-dedicated railway line with total length of 12,000 km, covering four vertical and four horizontal lines[1)]. In July 2016, the updated plan formulated an even larger blueprint of domestic high-speed railway network upon “eight vertical and eight horizontal” plan, with the total length increasing to 30000 km in 2020, covering 80% of big cities in China.

1) Four vertical lines: Beijing–Dalian, 1612 km; Beijing–Shanghai, 1318 km; Shanghai–Shenzhen, 1650 km; Beijing—Hong Kong, 2350 km. Four horizontal lines: Qingdao–Taiyuan, 906 km; Xuzhou–Lanzhou, 1346 km; Shanghai–Chengdu, 1922 km; Shanghai–Kunming, 2264 km.

Table 3 Introduction and absorption of high-speed trains

EMU trains (domestic player)	Collaborative actors	Mode	Series of EMUs
Harmony electric CRH1 EMU (CSR)	Qingdao Quartet of CSR—Bombardier (Canada)—Bauer Railway Transport Equipment Co., Ltd.	Sino-foreign joint ventures	CRH1A, CRH1B, CRH1E
Harmony electric CRH2 EMU (CSR)	Kawasaki Heavy Industries and CSR	Co-development	CRH2A, CRH2B, CRH2E, CRH2G, CRH2C
Harmony electric CRH3 EMU (CNR)	Germany's Siemens and Tangshan Railway Passenger Train Co., Ltd. of CNR	Co-development	CRH3C
Harmony electric CRH5 EMU (CNR)	Alstom of France and Changchun Railway Passenger Train Company of CNR	Co-development	CRH5A, CRH5G, CRH5E

Fig. 1 CRH380A

3.3 Engineering on bridges and tunnels

The powerful engineering and manufacturing of bridges and tunnels are necessary to complete the major high-speed railway line and cover complex terrain differences among diverse regions, such as mountains, desert, hills, plains, and basins. Representative bridge and tunnel engineering projects are described in Table 4.

4 World leader of innovative enterprises: CRRC

CRRC was merged by the oligopoly players CSR and CNR at the end of 2014 and became the world's most competitive enterprise in high-speed rail industry. Tracing to the strategic evolution of CRRC[1)], CRRC focused on the improvement of core competence and the development of innovation system. At the initial stage of CSR before 2004, it mainly concentrated on the integration and reconfiguration of existing resources. Thus, CSR enhanced the high-valued resources that cover in domestic high-speed rail industry, thereby constructing the basic competence pools for developing high-speed rail industrial goals. When China began the "introduction, absorption, and re-innovation" strategy to drive the high-speed rail industry, CSR positioned its strategy on enhancing the core competence via the introduction, absorption, learning, and re-innovation of high-speed technologies. CSR accelerated the leveraging of its own competitiveness via the investment of financial capitals and management system construction to promote the advancement toward the global innovative incumbents. Early in 2008, China transformed its high-speed rail industrial strategy into indigenous innovation. As a result, CSR shifted its strategic focus to indigenous R&D and the development of high-speed train brand

1) CSR is regarded as the basis of the group body and the core businesses of CRRC. Thus, we target the core competence of CSR to represent the CRRC before its establishment.

Table 4 Major bridge and tunnel projects for high-speed railway in China

Engineering projects	Representative projects	Descriptions
Bridge projects	Dashengguan Yangtze River Bridge	#Important part of Beijing–Shanghai high-speed railway and is the key channel in crossing the Yangtze River. #The total length is 9273 m, with six-span continuous steel truss arch bridge. #The maximum span between the main piers reaches 336 m, which is the world's highest span among bridges that support 300 km/h high-speed transportation. #Costs 300000 tons of steel and 1.26 million m^2 of concrete to construct the bridge. # Presented with George Richardson Award in 2012 by International Bridge Association, which is the top award within the global bridge engineering domain.
	Bei Pan River Bridge	#The first bridge of Shanghai–Kunming high-speed railway. #The main span reaches 445 m. #World's maximum span of reinforced concrete arch bridge and maximum span of high-speed rail bridge and achieved world record on rigid control of long span bridge. #Completed and opened for operation on November 19, 2015.
Tunnel projects	Xi'an–Chengdu Tunnel	#Connecting the high-speed railway from Xi'an to Chengdu. #Crossing 135 km Qinling Mountains. The total length of the tunnel is 127 km, covering six special tunnels with more than 10 km, in which Tianhua Mountain Tunnel is the longest.
	Dadu Mountain Tunnel	#Connecting Shanghai–Kunming high-speed railway. #The total length is 12 km, crossing special geological area, such as the karst geological area. #The tunnel passes through limestone, mudstone, marl, sandstone, and other strata, including seven major geological faults, eight fracture zones, and four contact points of soluble and non-soluble rocks. Builders face 44 caves and 1 underground river, in which the largest cave measures 330000 m^3.

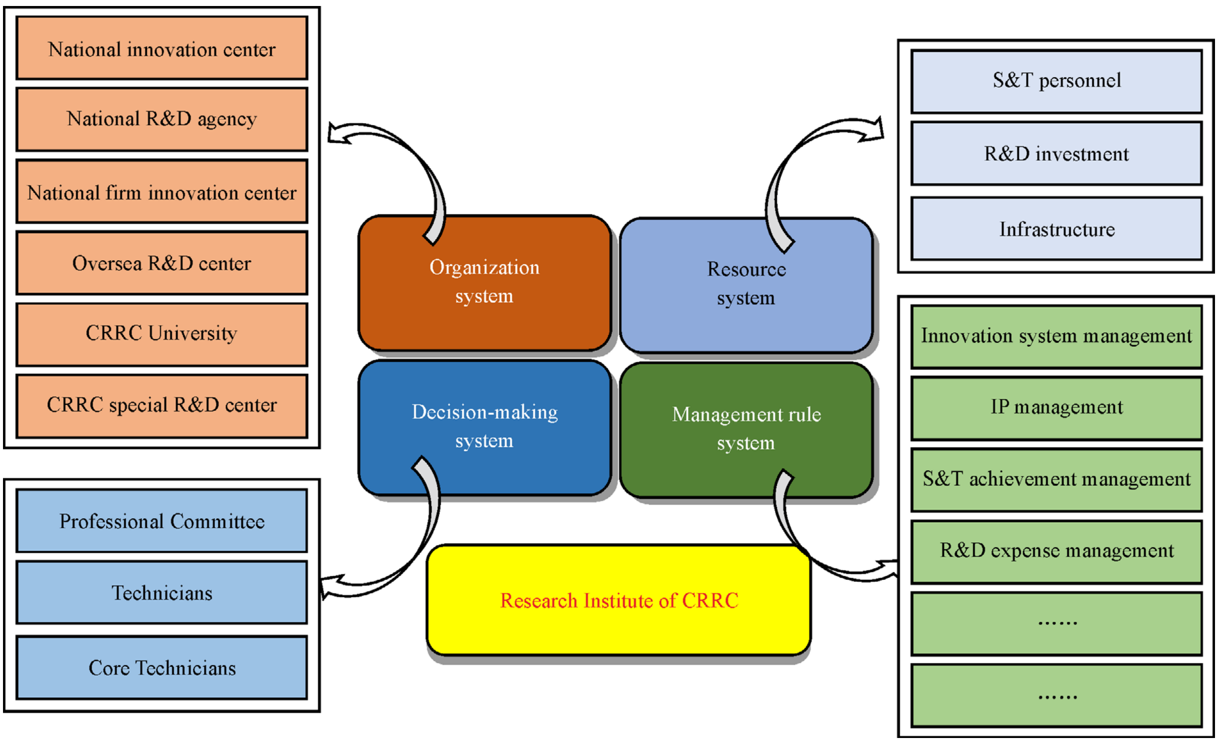

Fig. 2 Technological nnovation system of CRRC

CRH380, resulting in the construction of its global core competitiveness. Finally, the establishment of CRRC witnessed China's global leading enterprise in high-speed rail industry. CRRC began to output its indigenous technologies, high-speed train products, solution services, and manufacturing capabilities all over the world, thereby achieving sustainable development by balancing domestic and foreign businesses.

In addition, during the development of CRRC, the enterprise highly emphasized the innovation system constructions and established a comprehensive technological innovation system that involves the organizational, resource, decision-making, and management rule systems, to support the developments of high-speed rail's full technology chain, full product chain, and full innovation service chain. Figure 2 describes the technological innovation system of CRRC.

5 Conclusions

China's high-speed rail industry has advanced and surpassed the global competition. After years of efforts upon indigenous R&D, introduction and absorption, and indigenous innovation, China has completed the construction of its high-speed rail industry system, which not only outputs its standard EMUs to domestic and global markets upon fully indigenous technologies, but also establishes the world's most comprehensive high-speed railway network covering more than 80% of the country's major cities. In addition, the key player of China's high-speed rail industry, CRRC, has leveraged global competitiveness and outputted its products and manufacturing capabilities all over the world. High-speed rail has become the representative case sustaining the great power for the country.