ISSUE 12

KOTI Knowledge Sharing Report

KOREA'S BEST PRACTICES
IN THE TRANSPORT SECTOR

Korea's High-speed Rail Construction and Technology Advances

Edited by CHOI Jin-Seok

KOTI THE KOREA TRANSPORT INSTITUTE

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KOTI Knowledge Sharing Report: Korea's Best Practices in the Transport Sector

Issue 12: Korea's High-speed Rail Construction and Technology Advances

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He served as Chief Researcher at Korean Railroad Research Institute (KRRI), Executive Director at KHSRCA (Korean High Speed Rail Construction Authority) and KNR (Korean National Railroad).

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• Preface

South Korea started to examine high-speed rail (HSR) construction as a means to reduce the regional development gap that appeared in the industrialization process, the social cost of congestion, environmental pollution and accidents. Controversy regarding HSR construction appeared in the late 1980s, but the project was approved in the mid-1990s with detailed action plans. In 2004, despite of many political and social variables, Korea has finally become an HSR country with the launch of KTX. Now, ten years later, it is hard to examine whether the expected outcome has been fully completed or not. However it is certain that there has been an increase in inter-regional movement and rail mode share with a decrease in car accidents and dependence on fossil fuels.

It is inappropriate to directly compare South Korea with countries that previously adopted HSR, such as France, Japan and Germany, as South Korea had to rely on advanced countries rail technology while other nations developed their own. Even though it was a falsehood that South Korea was completely ignorant about rail technology, the level of technical skills was far behind to construct, produce and operate high-speed rail. Against this backdrop, Korea's decision makers set another goal for HSR construction; secure advanced railroad skills. Although this effort triggered some problems such as a delay in the KTX opening, it ultimately turned out to be the momentum which advanced its skills to a higher level that is competitive in the world railroad market.

Currently, South Korea's railway technical standards are homegrown with infrastructure construction, production of various equipment, operation and maintenance, and this standard can make inroads into the world market. This work examines how South Korea, which remained as an underdeveloped country in terms of railroad skills, could develop domestically produced technical skills based on the construction of a high-speed railroad. My desire is that this work will convey hope to countries that exist with underdeveloped railroad skills and will become a foundation stone for helping the railroad technical cooperation with South Korea in the future.

March 2014

Kim Gyeng Chul

President

The Korea Transport Institute

CHAPTER 1

Status of Korean Railway Technology

Since the high-speed rail (hereinafter referred to as “HSR”) system was adopted from France, Korea has been carrying out a domestic Korean high-speed rolling stock R&D project which aims to develop locally optimized high-speed rolling stock by integrating domestic technologies based on the technologies transferred from France for opening the Gyeongbu HSR in 2004.

The development of Korean high-speed rolling stock first began in the 1990s in the process of HSR technology transfers which were carried out as part of the National Policy’s Advanced Technology Development Project. The G7 Project aims at developing domestic technology at a G7 nation level. Since then, the project has transitioned into gaining support from the Ministry of Construction and Transportation, the Ministry of Commerce, Industry and Energy and the Ministry of Science and Technology for the development of a high-speed rolling stock capable of over 350 km/h in cooperation with various research institutes and academic universities as well as private enterprises. During the 1st phase of development (1996-2002), the focus was centralized on the design and manufacturing of high-speed rolling stock. Major achievements during this period include the development of a unique model from the design and system core, a success rate of 92% of components domestically produced, and 87% nationalized. Korea has become the world’s third nation following Germany and France to develop a 1,100 kW high power induction motor and power converter, and further developed car body manufacturing technology using aluminum-extruded panels for lightening vehicle weight.

Table 1.1. **Comparison of core technology**

Major items	Korean high-speed train	Gyeongbu high-speed train
Max. speed	350 km/h	300 km/h
Passenger car body	Aluminum-extruded panel (light weight)	Mild steel (Steel)
Traction motor	Induction motor	Synchronous motor
Propulsion control	IGCT type element applied	Thyristor type applied
Operation control	Digital	Analogue
Brake control	Electric control (accurate control)	Hydraulic control

During the 2nd phase of development (2002-2007), the project primarily focused on commercialization, and testing and commissioning (T&C) was carried out with traveling over 200,000 km in order to ensure safety and reliability. Particularly, a maximum speed of 350 km/h was achieved between Osong Station and Cheonan Station on the Gyeongbu HSR. Accordingly, the development of the first Korean commercial high-speed train (KTX Sancheon, Honam high-speed train) was successful.

Based on the Korean high-speed train developed in the previous project, many components of the KTX-Sancheon high-speed train were upgraded to

Figure 1.1 **High-speed train developed by domestic technology**

KTX-Sancheon high-speed train | Honam Line high-speed train improve performance, function and reliability, with technical modifications being applied as well. On one hand, problems in the existing high-speed train were improved for manufacturing, and the KTX-Sancheon high-speed train was estimated to be dominant in both technology and price in an international competitive bid against Alstom, France, with a final procurement agreement of 100 cars from Korea in 2006. This is noteworthy as prior to the technology transfer from France, Korea had no prior technical information on high-speed trains. Yet a decade later Korea was able to overtake their technology donor through its efforts.

When it comes to major improvements and changes to Korean high-speed trains, the design opted for double-heading with a structure of a 10 car formation plus 10 car formation, in lieu of a 20 car formation of the existing high-speed train. In addition, Korea developed elements of the propulsion system, reducer, power transmission gear, signaling equipment, and public address system (PA), and all seats in deluxe cars and standard cars were designed as rotary type. Also convenience facilities such as the dining car, lounge car, and restrooms were upgraded.

Since 2013, the next generation high-speed train, the HEMU-430X, is under development. It is a multiple unit high-speed train with locally developed technology as multiple unit stood in the spotlight of global markets in the 2000s due to its excellent capacity. This project, which is aimed to develop a 400 km/h multiple unit train utilizing domestic local technology, is supported by the Ministry of Land, Transport and Maritime Affairs (MLTM) and hosted by the Korea Railroad Research Institute (KRRI) in cooperation with academic universities, research institutes, operators, rolling stock manufacturers and part suppliers. During the 1^{st} phase (2007-2012), design, manufacturing and the testing of high-speed trains were the primary focus. Major achievements during this period include the development of a unique model from design to core system and the development of 400 km/h multiple unit propulsion, braking and control systems. The goals of the 2^{nd} stage (from 2012) including ensuring safety and reliability through testing and commissioning with proven travel over 100,000 km and achievement of 421 km/h of maximum speed occurred

Figure 1.2 Next generation high-speed train (HEMU-430X)

between Singyeongju Station and Dongdaegu Station in 2013. In 2014, a high-speed train will be tested at more than 430 km/h on the Honam HSR with good track conditions (flat track, turnout passage speed limit, etc.).

CHAPTER 2

Strategy for Technology Transfer of Korean High-speed Railway

This chapter describes the technologies which were acquired by Korea throughout the process of introducing HSR commercial service, troubles faced during the project, solutions, and achievements. This chapter will primarily focus on the efforts and plan for acquiring the technology rather than academic analysis, direction guidelines or specific technology transfer.

When it comes to railway technology, the balance of superstructure and substructure is characteristically essential and interface management is of importance as well. Korea obtained substructure technology such as civil engineering and track before the introduction of HSR. Unfortunately lacking was manufacture-related technology such as rolling stock, signaling and catenary which formed the strategy for technology transfer. Meanwhile, even if the design for test track sections passed through design verification by foreign engineering teams, it gave an opportunity of training substructure-related engineers such as civil engineering HSR.

1. Necessity of Technology Transfer

When the introduction of HSR was determined, the technology levels of Korean railways could be judged by the train traveling speed and electrification rates. At the time of planning the HSR, the maximum travel speed in Korea was 150 km/h and electrification at 50% (60.5% by 2011, 73% target for 2020). At that time locomotives, passenger and freight cars were exported under the circumstances that price was more significant than technology in global railway markets. Viewing the conditions of traffic policy in Korea, the priority of railway investment remained low and the railway was commonly considered a declining industry. Accordingly, there was yet no national consensus on the need of HSR construction in Korea. As such, railway personnel experienced difficulties in explaining the need of HSR to the nation.

On the other hand, there was a debate in establishing a strategy for HSR technology transfer. The debate was so-called 'Total vs. Core'. The keynote of 'Total' was that Korea had no experience in HSR construction or operation, so an all-encompassing commitment of design, manufacturing and construction of superstructure and substructure would come from a HSR technology-possessed country. Whereas the concept of 'Core' was that the introduction of an HSR should be categorized into two sectors; one which Koreans could carry out (Non-core: mainly civil engineering work/track) and the other which would rely on foreign technology (Core: rolling stock/signaling/catenary manufacturing etc.). The concept of 'Core' was finally accepted considering the project's budget reduction and the efficiency of core technology acquisition. Therefore, it was decided that the technology transfer was intensively focused on rolling stock, signaling, catenary, and telecommunication. Consequently France, Germany and Japan, which were interested in exporting their HSR, were invited for a bid.

Meanwhile, South Korea planned to learn technology in the process of industrial production. This means the RFP (request for proposal) specified that technology transfer and localization should be carried out in the process of production through local assembly and local part procurement. As for civil engineering, it was determined to be helpful in pushing into overseas markets in the future, based on the technology and experience that could be obtained by carrying out design and construction simultaneously. In the long run, the HSR was introduced with the strong will that this country should upgrade the level of technology and train technical professionals based on the construction of HSR and technology transfer of the concerned sector. As an effective action plan, the first priority of the HSR project was "technology transfer" in order to "secure the ability through the OJT (on-the-job-training)."

It was determined that technical dependency would be dangerous after the introduction of HSR, so all efforts were made to avoid it. At that time, 'Spanish HSR Operation' was set as the benchmark. Once operation and maintenance depend on the technology-possessed country, this would be a considerable burden on operation profits, and if the components are not supplied smoothly the worst situation could include operation stoppage. Therefore, it was required to secure the operation with sufficient profits through smooth supply of maintenance parts equivalent to or better than as well as the acquisition of operation skill. Considering such a situation, we could understand the necessity of technology transfer, and some concepts were embodied and specified in the contractual terms and conditions in order to promote technology development and pushes into overseas markets. Accordingly, a core goal was to domestically produce over 50% of parts initially increasing to over 95% of parts in the final train formation, based on an unprecedented technology transfer and manufacture. In addition, a clause to guarantee the rights of domestic production and sales and the right to push these products into overseas markets was also specified.

2. Concept of Technology Transfer

Technology transfer has to be understood as a process, not a singular event. This means technology transfer is difficult to be carried out by only securing technical documents or through technology study. Technical experience, namely technical know-how, can be transferred only in the course of a human relationship based on mutual faith. For instance, if some core data is missing despite receiving all technical documents, difficulties could arise at the stage of practical design and manufacturing and potentially creating substantial delays to solve such problems.

Based on the characteristics of technology transfer as aforementioned, it therefore should be stipulated in the contract in order to secure validity. To prevent a technology donor assuming a negative attitude to the technology transfer due to concerns of a boomerang effect, it should be specified clearly in the contract that contract fulfillment must be achieved. Japan stuck to their position not to transfer technology even if the RFP specified that the technology transfer was a “national interest” as a significant evaluation factor. Although Germany and France accepted such conditions, it was practically difficult to systematize a way to guarantee an efficient technology transfer. Namely, there were limitations in establishing a standardized assessment system verifying both the technology transfer and technology understanding are carried out properly. Accordingly, the best solution to guarantee technology transfer was to target and test locally produced products. Furthermore, an agreement on technology transfer by part unit was entered into by or between the technology donor and the recipient, and the contract came into effect “after approval from the client.”

Korea also succeeded in obtaining a guarantee for domestic production and sales of the transferred technology. It was because if the nation doesn’t have the rights to use the technology despite a complete transferring of such technology, it would be meaningless. Domestic production was carried out taking economic feasibility into consideration. For example, general technology transfer method was not applied to parts requiring a huge investment because localized parts sometimes became more expensive than imported ones even if local production was successful. On this basis some insisted that it was desirable to import reasonably priced products for use. However, it was more persuasive to protect again high prices set by a monopoly if domestic production capacity is lacking.

Major contracts for technology transfer to which the above principle is applied are as follows; first, technology transfer shall be carried out in accordance with the case-by-case contract for the technology transfer entered into by and between the donor and the recipient, but it shall obtain the approval of the Client (Korea High-speed Rail Construction Authority (KHSRCA)). Second, the domestic production goal is set at least 50% based on the price of manufacturing with the provision of a 20% penalty imposed on the shortage if the goal is not achieved. Also, based on parts over 95% of domestic production should be maintained in manufacturing the finalized train sets. Third, all the rights for the transferred technology shall include all the rights for design, production, manufacturing and sales, and sales rights in foreign countries except Europe and North America, were guaranteed. A limited sales right was guaranteed in Europe and North America by mutual consent. Fourth, when it comes to intellectual property, the supplier's intellectual property right of the existing developed products shall be highly esteemed, but the right to use the products in Korea was permitted. Intellectual property right acquired or obtained in the process of project after signing the contract shall belong to the domestic client, but the supplier or developer should have the right of use in principle. Last, regarding joint technology research, joint research for ten items, such as the technology development for next generation HSR (with 350 km/h), was guaranteed.

3. Scope of Technology Transfer

The scope of technology transfer was decided by using a technology tree analysis. It means that an accurate assessment of Korean technology was carried out in advance to evaluate the scope of technology transfer in order to improve the (technology) competitiveness in the whole railway industry. Finally, as aforementioned, the object of technology transfer included rolling stock, signaling and catenary, which were defined as 'Core', and since then the technology transfer was mainly focused on the above sectors. Substructure such as construction and civil engineering work was excluded from the concept of 'Core' because Korea, at that time, had its own technology for the project. Nonetheless, it was decided to actively accept such technologies and 'Core' interface management technology.

A good example was the design verification of substructure such as civil engineering work and track. As aforementioned, the design and construction of substructures, which were mainly related to the construction of track and civil engineering work such as bridges, were carried out with domestic technology. However, advanced technology was required for design criteria and its verification related to dynamic behavior which could occur when operating a partially-vulnerable rolling stock. Finally, technical problems occurring during the design and construction of the test track section (Cheonan to Daejeon) were observed and solutions were applied to the entire section. As predicted, some design problems such as an abrupt and dynamic behavior of a bridge were discovered during the construction of test track. French Systra, with an abundant experience in HSR design, was requested to carry out design verification. Test track construction was completed through safety validation and partial design change. In the process of this design verification, Korean engineers acquired the design ability to solve the dynamic behavior that occurred during the operation of high-speed trains, obtained the various criteria necessary for the design of civil engineering and track, and learned the know-how of incorporating them into the construction.

Unlike substructure, the strategy for core equipment such as rolling stock was to acquire as much advanced technology as possible. Namely, the strategy was to have a correct understanding of the technology gap and bridge this from advanced countries in the arena of HSR in order to catch up as soon as possible. Target technology included all technology required for future business such as design, manufacturing, T&C, and O&M (operation and maintenance) skill, and therefore, bidders were requested to describe the details of target technologies in the proposal. Accordingly the countries of France, Germany, and Japan submitted proposals, but as some countries were reluctant to transfer technology, their particular proposals were given poor evaluated scores. At that time, Korea focused on four technology sectors classified as core technology (refer to Table 2.1).

Table 2.1 HSR-related core technology

Technology	Technology name	Remarks
Engineering	• Core system engineering • System interface engineering • Research & development	• Technical conditions required for design • Technical condition for inter-operation between sub-systems to ensure HSR safety • Research on next generation HSR
Rolling stock design and manufacturing	• Rolling stock system engineering • Rolling stock design/manufacture/test, train set assembly, part design/manufacture/test	
Signaling equipment	• Signaling equipment system engineering • Design/manufacture/test/construction of ATC, CTC, IXL	
Catenary	• Engineering, design/manufacture/test/construction	

Project management technique, in addition to this core technology, was also classified as an important technology and selected as the technology to be transferred. Although systematic project management was essential to carry out a large scale construction project, the importance was not yet recognized. Originally, project management is an important part of achieving project goals using organic and systematic management techniques in order to secure the required quality with a fixed budget and within the project schedule. However at the beginning of the project, Korean engineers insisted that project management had been carried out previously and could be conducted again. Thus, they warned about the risk of wasting foreign capital and there was considerable internal resistance to applying the project management technique. But as there was a limit to the existing management technique during the construction of test track, the nation understood the importance of a management project and thus possessed an efficient project management method in cooperation with Bechtel, the specialized project management company, by changing from a consulting service to a joint project management service. Originally it was not planned but added as a result of recognizing the necessity of project management during construction. It gave the opportunity of eliminating the rigidity which might occur during execution of a large project. Since then, Korea possessed high technology by expanding an independent project management technique to the overall railway industry. The project management is categorized into six parts: document control, project cost management, schedule management, contract management, design management, and construction management and quality control. All have been standardized as a matrix system.

4. Subject of Technology Transfer

Generally, there was no standard model for technology transfer, and it was predicted that the effects of a technology transfer would depend on the recipient's understanding of technology and investment scale as well as the contents and the level of technology to be transferred. On the basis of this understanding, the methodology of technology transfer was based on the document describing the position between the technology donor and the recipient in accordance with the contract. Consequently, the donor judged its value within their technology scope and the recipient evaluated the actual value of technology provided and the future prospect of technology in order to determine a basic structure of technology transfer.

At that time when Korea reviewed the introduction of HSR, there were only three countries; France, Japan and Germany, which had already succeeded in commercial operation service of HSR. Consequently, at the planning stage of the Gyeongbu HSR construction project, Korean railway industries reviewed their HSR technology and classified necessary technology, then began to prepare an RFP for technology transfer and localization plan. After evaluating the bids French Alstom was selected as the preferred bidder, and finally designated as a contractor through negotiation between the two parties lasting approximately a year. For rolling stock other part suppliers including Alstom were determined as technology donors, for signaling equipment the manufacturers of ATC, CTC and IXL were decided, and a catenary manufacturer was decided as well.

The technology recipient was categorized into private and public sectors. The private sector had the responsibility for design, manufacturing, installation and testing, whereas the public sector (operator and constructor) was responsible for commissioning, operation and maintenance which couldn't be carried out by the private sector. The recipients had design abilities and manufacturing in the related technology field and most recipients were existing railway part manufacturers. The technology transfer was carried out through a technology partnership, joint venture or other legal methods. For rolling stock, the strategy for technology transfer was established so that Hyundai Precision & Industries Corporation, Daewoo Heavy Industries, Hanjin Heavy Industries and local part suppliers could participate. Samsung Electronics and LSIS were responsible for signaling equipment, and LG Cable was responsible for catenary. Alstom was a donor of rolling stock technology and the recipients per part are shown in Table 2.2 below.

Table 2.2 Recipients of technology possessed by Alstom

Item	Donor	Recipient
Power car	Alstom	Hyundai Precision & Industries Corp., Daewoo Heavy Industries
Passenger car		Hyundai Precision & Industries Corp., Daewoo Heavy Industries, Hanjin Heavy Industries
Motorized trailer		Hanjin Heavy Industries
Bogie		Hyundai Precision & Industries Corp.
Bogie frame		Hyundai Precision & Industries Corp.
Traction motor		Daewoo Heavy Industries
Power control system		Hyundai Heavy Industries, Daewoo Heavy Industries (inverter)
Electronic control		Samsung, Hyundai Electronics, LG, Hanyang Electronics, YUJIN, Hyosung Industries, DAYUNG
Freon Tank		Hyosung, Kwangmyeong, Hyundai Heavy Industries (electrical), YUJIN, Daewoo Heavy Industries
On-board computer		Samsung Electronics, Hyundai Electronics, LGIS, Hanyang Electronics, YUJIN, Hyosung, DAYUNG
Auxiliary motor		Hyosung Heavy Industries, Hyundai Heavy Industries, Daewoo Heavy Industries
Electric equipment		WOOJIN, Kwangmyeong, Hyundai Heavy Industries, YUJIN, Hyosung Heavy Industries, Icheon Electric, Daewoo Heavy Industries

Table 2.3 shows the donors and recipients of technology not possessed by Alstom.

Table 2.3 Donors and recipients of technology not possessed by Alstom

Item	Donor	Recipient
Doors	FAIVELEY	Donghwa, Hosan, WOOJIN, Mando
HVAC	FAIVEL STONE	Daewoo Carrier, Mando
Main converter	GEC-ALSTHOM	International Electric, Hyundai Heavy Industries, HICO
Brake	SAB Wabco	YUJIN, Mando, Hosung
Wheel	VALDUNES	Kia
Window	KLEIN	Korea Magnesium, HDC (Hyundai Development Company), Hyundai Aluminum, Daewon Safety Glass
Seat	COMPIN	DAEWON, Hanil-Ehwa
Audio/ video	ELEC/ELNO	Daewoo Electronics, Hyundai Electronics
Battery	SAFT France	SAFT Korea, GLOVAL Yuasa
Pantograph	FAIVELEY	YUJIN, Mando

Tables 2.4 and 2.5 show the list of donors and recipients for signaling equipment and catenary technology, respectively.

Table 2.4 Donors and recipients of signaling equipment technology

Item	Donor	Recipient
ATC • Hardware • Software • CMS	CSEE Transport	LGIS
IXL • Hardware • Design • Software	Alstom	Samsung Electronics LGIS Samsung Electronics
CTC • Hardware • Design • Software	Alstom	LGIS

Table 2.5 Donors and recipients of catenary technology

Item	Donor	Recipient
Catenary	CGELEC SA	LGIS/ILJIN Electric

5. Procedures for Technology Transfer

The goal of HSR technology transfer carried out in line with the introduction of HSR was to acquire advanced HSR technology through domestic manufacturing of core equipment, improve the transferred technology to local technology and develop a next generation HSR independently without the help of foreign technology. Therefore, the approach to realize it efficiently was to design the technology transfer process in detail and incorporate it into the contract. At that time managers considered the technology transfer would be based on manpower training and accumulation of experience so they made a detailed action plan. First, a training plan was classified into design, manufacturing, testing and commissioning and a technology tree was prepared. Also a training course for technology transfer items was developed, the instructors chosen, the training period decided, and recipient's required qualifications and work experience was defined.

Technology transfer was divided into three stages; the handover of technical documents, training including OJT, and local production and test evaluation under technical guidance and supervision. Through the handover of technical documents at the 1st stage, all drawings related to design, manufacturing, testing, and technical documents such as various capacity calculation sheets were transferred to the recipient on a step-by-step basis for a preliminary review. Alstom, as a leading company, better understood the terms and conditions of the contract and was cooperative. However, even if there was a conflict in the process of technical document handover at the level of part unit between the donor and the recipient, due to a misinterpretation of contract, the client acted as an arbiter for reviewing the handover process in lieu of the recipient. During the 2nd stage related experts, who received the documents and studied them in advance, were sent to France in order to get OJT training at the production site when manufacturing two train sets for the first time in line with theoretical instruction. After returning to Korea, they acted as instructors to train engineers who would participate in locally manufacturing 34 train sets in Korea and also acted as key personnel who

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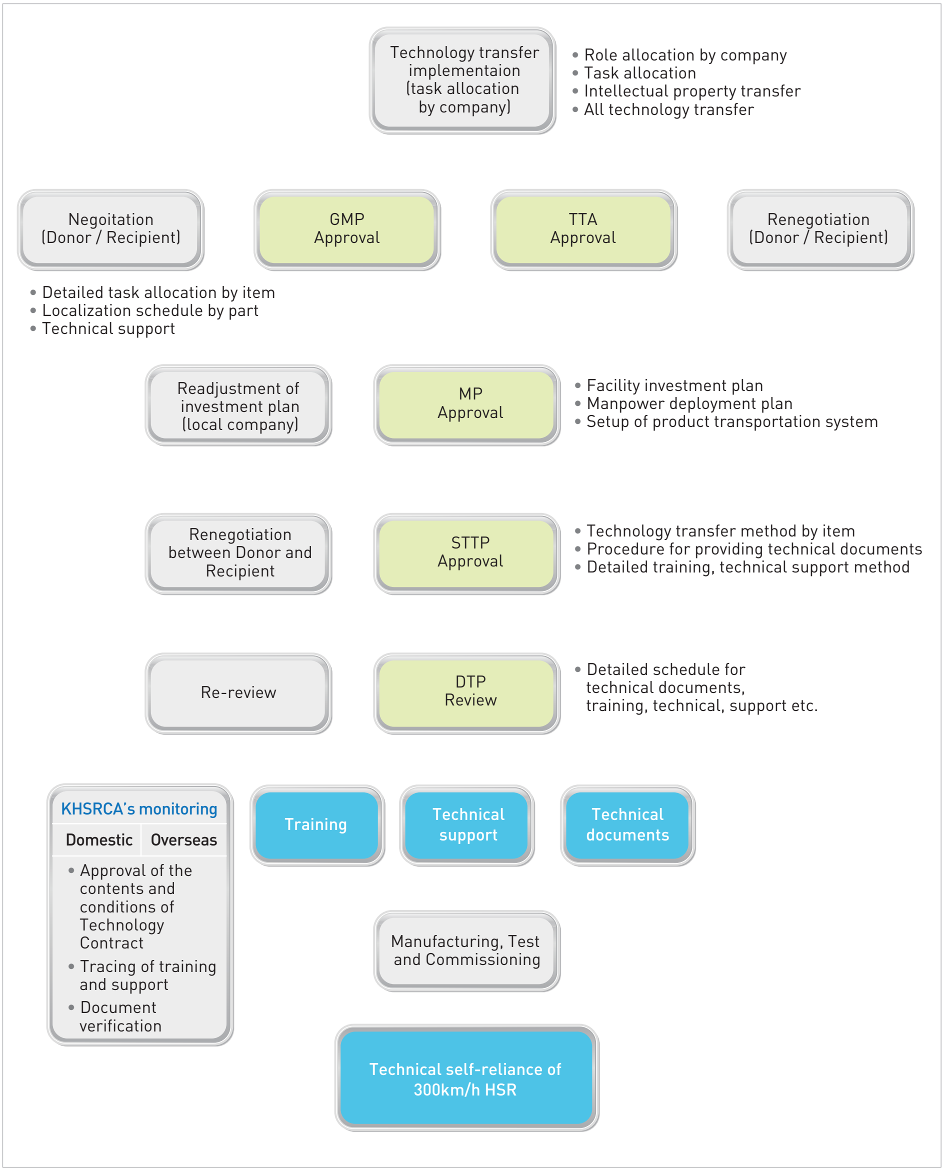
Figure 2.1 Technology transfer flow chart



were responsible for propagating the transferred technology in Korea.

Curriculum consisted of 27 courses for the railway operator and 300 courses for manufacturers and a considerable portion of the curriculum was supplemented during the technology transfer. For traction equipment as core part of HSR, a 58-week long-term course was held, whereas there was also a 4-week short-term course for train operation.

Table 2.6 Railway operator training course

Classification	Training curriculum	No. of trainees and duration	
		Trainees	Total weeks
Rolling stock	O&M mangers	10	60
	Trainers	14	728
	Technical leaders	20	160
Signaling	Mangers	2	12
	Train control operation	6	60
	Train control maintenance	90	1,080
Catenary	Managers	2	8
	Catenary O&M	90	720
Operation	Drivers' trainers	4	60
	Drivers	8	48
	Train crews	5	20

Prior to instructors teaching training courses, they underwent an evaluation course categorized into three stages consisting of preliminary evaluation, evaluation during the training, and evaluation after training to verify technical improvement and maximize the effectiveness of training. During the 3rd stage, French engineers were dispatched to Korean production

Figure 2.2 OJT (on-the-job-training)

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or testing sites to give technical instruction to engineers on manufacturing 34 train sets.

Although Korean engineers were responsible for manufacturing 34 train sets locally in Korea, the technology donor still had the responsibility for performance and quality of products, so that Korea could acquire as much technology as possible. Furthermore, Korean researchers participated in 11 core research projects for the next generation HSR therefore paving the way for a future independent development of HSR through joint research. Even though Korean engineers underwent technology transfer training, local companies experienced many difficulties as seen when French engineers judged the results at the beginning stage of HSR technology transfer. Nevertheless manufactures accumulated technology through such trial and error.

Table 2.7 Training period and institute by research project

Research Project	Period	Research Institutes	No. of personal
Micro pressure in normal state	1 year	Aix-Marseille University	1
Micro pressure in abnormal state	1 year	ESI R&D Center	1
High performance brake disc	1 year	Valenciennes University	1
Carbon/carbon brake system	1 year	LML University (Lille)	1
Eddy current brake	1 year	LEEP LITTLE R&D Center	1
Acoustic engineering	1 year	Poitiers University	1
Collision	1 year	IPSE of Valenciennes University	1
Superconductivity	1 year	CNRS-CRTBT (Research Center)	1
Propulsion system element	1 year	ECL R&D Center	1
Artificial intelligence	9 months	Pierre-and-Marie-Curie University	1
Data processing system	9 months	IRISA R&D Center	1

Many difficulties were experienced in verifying the evaluation of technology transfer. The goal of the transfer was to develop abilities to precisely reproduce the product through design, manufacturing and testing. Therefore it was decided to evaluate the effect of technology transfer based on indicators in the process of domestic production. The 1st indicator specified that domestic production should be 50% or more based on the price of manufacturing while the 2nd indicator specified that local production should be maintained over 95% at the final stage of the domestic production. Although measurements would be exact, there was a debate as to how 95% should be calculated, either by unit price or accounting. Even though the technology transfer was completely carried out without exception, from an economic aspect it could sometimes be undesirable to localize all components. Accordingly it was specified that related product items would be assembled, manufactured and tested through the technology transfer, they wouldn't be localized. In other words, the employer clearly identified the scope and level of items for technology transfer and localization and it was reflected elaborately in the contract during the negotiation of technology transfer as it was more economical to import and assemble parts not widely used due to a huge investment in facilities. In other words, a huge investment in the facilities was required, but it was cost efficient to import frequently rarely required parts, so the scope and the level of technology transfer and localization were clearly incorporated into the agreement, with a clear definition of the client.

Measuring the effect of technology transfer is difficult. Even though it's possible to quantitatively evaluate the number of technical documents transferred and the number of engineers trained, it is impossible to evaluate the effect according to the result of technology transfer itself. In summary, compared to what was planed Korea acquired 100.3% technical documents, 106.6% of the recipient's engineers were trained, and 115.1% of the donor's technical support and supervision was carried out.

Table 2.8 Result of synthetic evaluation for technology transfer

Classification	Planning	Performance	Ratio (%)
Technical data	352,145	353,370	100.3
Technical training	1,120	1,194	106.6
Technical support	892	1,027	115.1

CHAPTER 02

6. Results and Implications of Technology Transfer

The results of technology transfer can be estimated by the degree of goal achievement, summarized as possessing independent technology development abilities and having the ability to push into overseas markets. With the introduction of HSR, the Korean railway industry gained the ability to build and operate the HSR independently and is also capable of manufacturing the high-speed train internally. In fact, Korea has already secured its unique HSR-based technology by developing 350 km/h HSR technology based on 300 km/h technology. When it comes to the technology of high-speed train manufacturing, Korea's unique model named KTX-Sancheon has been in service after commercialization and currently another high-speed train with a maximum speed of more than 400 km/h is under development. Moreover, its commercialization is close at hand because the interface test for civil engineering work, track, signaling, catenary and rolling stock is in progress. As the Korean railway industry has the ability to build and manufacture HSR based on the above technologies, the road is clear for pushing into overseas markets. Records show that exports are on the rise and Korea is making an attempt to push into HSR markets in such places as Brazil and the U.S.

From the aspect of manpower, the introduction of HSR gave Korea an opportunity to upgrade and diversify local technical engineers thereby stimulating the revival of the local railway industry. For railway industries professional manpower in the arenas of civil engineering work, track, signaling and rolling stock should be in harmony through a cooperation system, ensuring the efficiency and safety of HSR. In the process of introducing HSR as a whole, technology was transferred to the construction companies, manufacturers, and part suppliers enhancing the specialty of employees working at those companies and currently they are playing a pivotal role in the Korean railway industry. It is attributed to the training of engineers through the training propagation by approximately 1,000 instructors who learned HSR-related technology

CHAPTER 3

Rolling Stock Technology Transfer

1. Before and After Contract Signing

The selection of rolling stock for Gyeongbu HSR began with sending a RFP to Japan, France and Germany in 1991, all of which had launched a commercial service. The draft of RFP was developed based on the technical investigation and basic design of HSR carried out by the Korea Transport Institute (KOTI) from July 1989 to February 1990 by request of the Korea National Railroad (KNR). Since then, a detailed RFP was prepared in cooperation with KOTI, Yooshin Engineering Corporation, KRETA, Hyundai Precision & Industries Corporation, and the Louis Berger Group in March in 1990. The RFP was modified and supplemented by the review of the HSR Construction Planning Team of KNR.

At that time, the scope of RFP included the rolling stock of maximum speed at 300 km, catenary and ATC which required cutting edge technology. All systems including rolling stock, catenary and ATC were considered to sufficiently ensure passenger capacity, high speed and safety as their characteristics were consistent each other. In addition, the RFP included the phased cutting edge technology transfer to have abilities independent of HSR development and also considerations in localization to raise the possibility of selling to a third country. It was decided to finalize the type of rolling stock through negotiation after reviewing the RFP and the RFP was modified and reviewed 6 times. Rolling stock type ignited a heated debate on a fundamental matter; wheeled or maglev. Finally, GEC-ALSTOM, the French TGV manufacturer, was selected as a preferred bidder in August 20th, 1993 with the rolling stock type being decided after signing the contract on June 14th, 1994.

In the early 1990's, TGV of France and ICE of Germany were using power car type and the Shinkansen of Japan was multiple unit type. Korea preferred multiple unit because at that time technical tendency was toward the multiple unit as it has an excellent capacity. In addition, Korea had interest in technology transfer in the process of selecting the type of rolling stock, but Japan continuously maintained a negative attitude towards technology transfer. That was why Korea decided on TGV's power car type. After many twists and turns, Korea developed a multiple unit Korean HSR through the technology transfer from France. Both of KTX 1 and KTX 2 (KTX-Sancheon), currently in service, are all power car type, and can be manufactured with our local technology. Furthermore, multiple unit vehicles were developed with Korean domestic technology in 2012 and are currently under test and commissioning. Therefore, it is expected that it will take a long period before pushing into overseas markets in the future based on the results of domestic commercial service. It is regretful that our country lacked the insight for future technology at the beginning of selecting the type of high-speed train.

After the type of rolling stock was selected, a preliminary preparation for technology transfer was to set up a negotiation team consisting of experts so as to acquire the necessary technology. The Korean negotiation team consisted of 57 members from 11 sectors and the French team comprised a total of 70 individuals. The negotiation for a contract on the introduction of rolling stock and core technology was carried out on a step-by-step basis lasting approximately 8 months from September 1993 with results confirmed on April 18th, 1994. Core items of confirmed result are shown in Table 3.1 below.

Table 3.1 Negotiation result of rolling stock technology transfer

Chapter 7 Technical

- Quality assurance and thorough commissioning
- Reinforcement of passenger facilities and comfort levels
- Replacement of air-conditioning refrigerant with next generation pollution-free refrigerant (R134a) to prevent air pollution
- Design of typical streamlined head appropriate for Korea's conditions

Chapter 8 Technology Transfer and Localization

- Technology transfer and localization over 50% of the manufacturing price
- Securing supervision rights of the KHSRCA in the process of all technology transfer and localization
- Application of 20% penalty on shortage if the goal of localization is not achieved
- Reduction of technology transfer fee: Upfront fee (free of charge), sales engineering fee reduced from 2.5%→2%
- Securing manufacturer's rights for manufacturing, test, sales and pushing into global market (however, mutual agreement needed for Europe and North America)

Chapter 9 Terms and Conditions of Contract

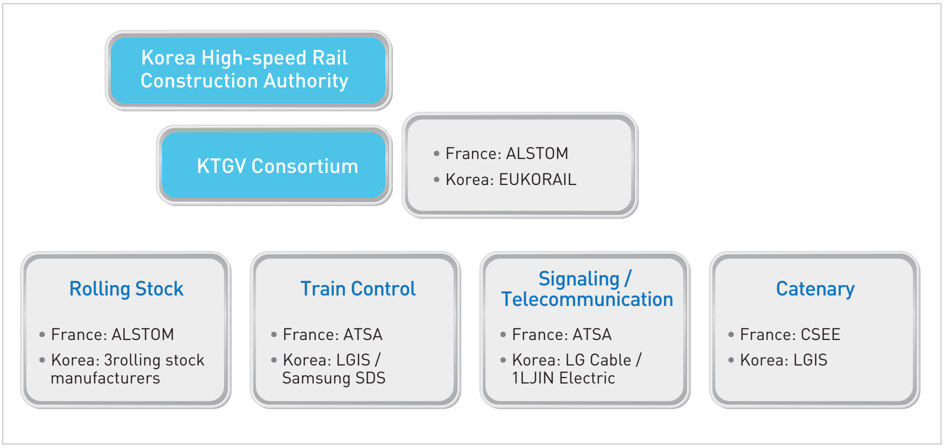
- Securing the rights of use for already developed technology and KHSRCA's ownership for new technology developed during the project
- 2-year performance guarantee after hand-over and 5-year repair warranty after signing the contract on unexpected faults
- Individual and joint responsibility for the entire project by consortium members
- Advance payment : 15% of off-shore, 10 % of on-shore, and payment every 2 months by activity
- Loan amount: 274 million USD, over 8 years with 10-year grace period. Details to be discussed with Indosuez Bank

At that time, eight local companies and four French companies were involved in rolling stock manufacturing under the above contract terms and conditions and the consortium was organized with them.

Table 3.2 Status of rolling stock manufacture participants

<table>
<tr><th>Classification</th><th>Companies</th><th>Supply</th><th>Remarks</th></tr>
<tr><td rowspan="8">Domestic</td><td>EUKORAIL Co. Ltd.</td><td>Consortium leader</td><td rowspan="8">France's Korea-based subsidiary</td></tr>
<tr><td>DAEWOO Heavy Industries</td><td>Rolling stock manufacture</td></tr>
<tr><td>Hanjin Heavy Industries</td><td>"</td></tr>
<tr><td>Hyundai Precision & Industries Corporation</td><td>"</td></tr>
<tr><td>LG Cable & System</td><td>Catenary manufacture</td></tr>
<tr><td>ILJIN Electric</td><td>"</td></tr>
<tr><td>LGIS</td><td>Signaling equipment manufacture</td></tr>
<tr><td>Samsung Electronics</td><td>"</td></tr>
<tr><td rowspan="4">Foreign</td><td>GEC-Alstom</td><td>Rolling stock manufacture and consortium leader</td><td rowspan="4"></td></tr>
<tr><td>GEC-Alstom Transport SA</td><td>Signaling equipment (CTC/IXL)</td></tr>
<tr><td>CEGELEC SA</td><td>Catenary manufacture</td></tr>
<tr><td>CSEE Transport</td><td>Signaling equipment (ATC) manufacture</td></tr>
</table>

Figure 3.1 Consortium organization and work scope



Alstom established a local subsidiary in Korea for the Gyeongbu HSR project and also organized a consortium for technology transfers.

For practical effects of the negotiation, our strategy was to focus as much as possible on favorable technology transfer conditions instead of price. In this regard, proposals were received from GEC Alstom of French, Siemens of Germany, and Mitsubishi of Japan six times over three years and continued back and forth negotiations. On June 14th, 1994 an agreement was entered between Korea High-speed Rail Construction Authority (KHSRCA) and Korea TGV Consortium (KTGVC) with GEC Alstom leading. The details of the technology transfer were specified separately. The contract specified that Alstom was obliged to transfer all related technologies which were not possessed by Alstom as well as TGV rolling stock manufacturing, catenary and control systems possessed by Alstom. Additionally, the contract specified that 34 of 46 train sets in total could be localized and localization portions of the local recipient designated by Korea were allocated at 50% of the total manufacturing price. As a result of this clause, the quantity of localization was minimal at the beginning of the project, but increased from the middle of the project to almost 100% of localization achieved at the completion of total train set manufacturing. A plan was prepared to ensure that the donor assumed responsibility for a 20% penalty if the goal of localization was not achieved ensuring localization could be carried out by Korean engineers.

Furthermore, the contract specified that Korean engineers could participate in 11 R&D programs in progress in France aiming at developing the next generation TGV technology. Korea acquired the rights of pushing into global markets and intellectual property rights, thereby paving the way for pushing into a domestic or overseas HSR market after the completion of the project in Korea.

2. Manufacturing, Delivery and Commissioning Phases

12 high-speed train sets, directly imported from France, were manufactured at eight factories including Alstom's power car factory in Belfort. A total of 10 manufacturing factories such as Charerois and auxiliary inverter factory in Belgium and inverter and battery factory in Preston, U.K. got involved. Other major part suppliers were eight companies including Stone Iberica in Spain. The 1st Korean TGV was opened to the public, for the first time, at GEC Alstom factory in La Rochelle, the west of France, on May 29th, 1997, and the 1st car was completely manufactured on July 22nd of the same year. It implies that the first assembled product was produced not later than 3 years and 1 month from the date of signing the contract on June 14th, 1994. The first completed Korean TGV passed all factory tests and started commissioning on the SNCF track in France from December 17th in the same year. The commissioning was mainly focused on performance checks and adjustments.

High-speed trains manufactured in France were separated by train unit then transported to Changwon factory rolling stock manufacturer in Korea and assembled again according to train set. Prior to the assembly of train set, single car tests (static, dynamic) on the power car, single car test of motorized trailer, and motor car + motorized trailer test (static, dynamic) were carried out. All the tests were carried out for the completely assembled train set at the factory in Korea for almost three months. After the completion of factory testing, performance of rolling stock was verified through 23 static and dynamic tests after running approx. 10,000 km (40,000 km for KTX 1, 2) at 300 km/h on a test track. After completing the performance, acceptance inspections were repeatedly carried out in Goyang Depot over six months from October 2003 to March 2004 before it was finally accepted by KNR.

Manufacturing high-speed trains locally in Korea began from October 1996, led by Korean Rolling Stock (KOROS). A total of 34 train sets (16 train sets in 2002 and 18 train sets in 2003), 680 cars and an additional 40 passenger cars were manufactured over five years. At the beginning of manufacturing, many trials, errors and difficulties were experienced in design, material and production taking about three years to complete one train set. However, the manufacturing period was later reduced by 1/3, based on years of experience and accumulated know-how.

Acceptance inspection began in August 2008 and the acceptance certificate was issued in October with acceptance of 46 train sets finally completed in March 2004. Initially it took two months to conduct acceptance inspection due to a lack of experience. However since February 2004 it took about two weeks to carry out acceptance inspections per train set through the integrated commissioning test.

Commissioning was carried out on the 57.2 km test track spanning from Sojeong Township, Yeongi County, Chungcheongnam Province to Hyeondo Township, Cheongwon County, Chungcheongbuk Province over 52 months from December 1999 traveling between 10,000 km to 40,000 km. For commissioning a total of 180 tests such as rolling stock adjustment test, performance test, acceptance test and integrated test were carried out by traveling at 40 km/h and gradually increasing the speed to 300 km/h. It was intended to verify technical interface between the track bed and track constructed with domestic technology and the rolling stock, catenary and signaling system constructed with French technology. Performance inspection and adjustment (traction system, triple braking system, airtight device etc.) for new technology parts were carried out in parallel. Furthermore, performance tests of current collection between the rolling stock and the catenary, and the safety inspection and adjustment of power supply were conducted as well. Particularly the performance adjustment of all power and electronic parts was carried out as the electric characteristics were different from France (50 Hz → 60 Hz).

3. Technology Transfer

The technology transfer of high-speed trains was divided into two categories. For technology transfers to KHSRCA, general matters on the high-speed train system including information required for the contractor, were classified into four categories spread over 18 months in France. The core system engineering section covered a feasibility study and general matters on the similar core system, whereas the system interface engineering section referred to the internal interface of the core system and the interface between the core system and subsystem or other systems, while the R&D section covered general matters on next generation TGV high-speed train systems under development. Lastly, the rolling stock section dealt with general matters on rolling stock. Technology transfer to KHSRCA was well carried out in detail which allowed the contractor to review and approve all kinds of technical documents. As Alstom, which required the approval of the KHSRCA for technical documents, had to provide KHSRCA with general high-speed train information, the training for the structure and design of high-speed train system was planned for the employees of KHSRCA. For technology transfer to the rolling stock manufacturer, it seemed that the manufacturer had to understand technical documents provided piecemeal to enable manufacturing and testing, but design know-how was excluded.

The technology transfer to the rolling stock manufacturer consisted of training held in France with technical instruction and manufacturing and testing supervision in Korea. Training in France was classified into design documents, procurement documents, production technology documents and quality control documents necessary for manufacturing and testing in Korea, but it was limited to the understanding of such documents. For example, a technical training for design began with a high-speed train engineering study beginning in 1995 and lasted four years ending with the power car interior design study in 1999. Training period for each course was from 1 week to 6 months depending on the subject, and the transferred technical documents included 25,000 drawings, various specifications and 1,700 procedures. Alstom dispatched its staff to provide technical instruction and supervision in Korea. They were involved in technical instruction, control and supervision from selecting the part localization supplier to the overall process such as manufacturing, testing and quality control in Korea in order to verify that the whole procedure was correctly carried out as trained. Something remarkable about technology transfer by Alstom was a huge volume of detailed work procedures and guidelines required for manufacturing, testing and quality control. Work management in Europe characteristically focused on work procedures and guidelines for work accuracy and methods to prevent errors, by focusing on a worker's individual skill, which was different from the Korean case where worker experience was important. Even if this method was, to some extent, more intricate than the existing vehicle manufacturing method, it helped to manufacture the Gyeongbu high-speed train in Korea from 1998 through 2003 without any quality problems.

CHAPTER 4

Construction and Civil Work

1. Railway-based Technology Before High-speed Railway Construction

General information on Korean railway technology and history is briefly summarized below. Railway technology was first adopted in Korea on September 18th, 1899 when Gyeongin Line spanning 32.3 km was launched between Incheon and Noryangjin in Seoul. Since then, railway technology has been improved gradually depending on traction power and speed performance of power car locomotives. When it comes to the technology level of conventional railways in 1989[1], the track facilities were improved for high-speed[2] service up to a maximum speed of 140 km/h (operational speed of 107 km/h, track maximum speed 150 km/h) running diesel locomotives on the Gyeongbu Line. The design for Honam double track between Songjeong-ri and Mokpo started in 1991 before adopting HSR. For the first time in Korea track facilities, including routes, were designed for speeds of 180 km/h. Therefore this technology level was considered to be higher than the aforementioned.

Electrification started in October 1968 with industrial lines such as

1) This is the same the HSR Planning Office for the HSR construction implementation was organized by KNR.

2) In the 1950s the maximum speed was 70 km/h with an operational speed of 50 km/h.

Yeongdong Line, Taebaek Line, Jungang Line as well as Seoul Metropolitan Subway which work commenced in 1970. In 1989 the subway had a length of approx. 670 km which accounted for 21.4% of total 3,120 km length in Korea. Train control and control systems have been rapidly upgraded to electrical signaling type from mechanical signaling type. ATO system such as CTC, ATS and ATC have been adopted in some urban railway sections. Technology infrastructure for the design, construction and operation of electrified railway, substation, train control and control system was evaluated to be high enough to accommodate HSR technology.

KNR was responsible for railway technology and its major function included railway rehabilitation as well as railway operation and construction. The organization and manpower of KNR consisted almost entirely of experts. The table below shows the detailed organization. In this way Korea had already retained railway engineers for each sector. Among them, competent engineers with abundant experience in railway operation and construction played the role of core engineers in the HSR construction. At that time, the maximum speed was 140-200 km/h on Gyeongbu Line, Honam Line and Jeolla Line, so railway design and construction technology were evaluated to be sufficient enough to accommodate the HSR construction.

Table 4.1 Railway technical parts and details

Technical part	Details
Operation technology	Operating machine sector for train operation and control
Construction and maintenance technology	Civil work sector for railway construction and improvement, track maintenance
Rolling stock technology	Mechanical sector for rolling stock design and maintenance
Control technology	Signaling and communication systems for train control
Power technology	Electrical sector for subway power, railway construction and improvement
Civil work technology	Civil work sector for track maintenance
Building technology	Design, new construction, maintenance of railway buildings such as stations

2. Phased Approach to High-speed Railway Technology

Korea began to have interest in HSR in 1963, the year before the Shinkansen Line (Tokyo to Shin-Osaka, 552.6 km) opened coinciding with the 1964 Summer Olympics taking place in Tokyo. At that time, Korean railway engineers participated in trial runs with a test train at a speed of 240 km/h. Afterward they prepared a report on the advantages and the need of HSR based on technical information about Japanese HSR, and submitted it to the Korean government. But Korea in those days didn't have a great interest in HSR because the transport policy was mainly concentrated on highways such as Gyeongin Highway and Gyeongbu Highway, etc. Nevertheless, Korean engineers, stimulated by Japanese HSR, started having great interest and intensively made efforts at speed improvement of the existing railway such as alignment improvement, track structure improvement and signaling system automation. As a result, the nation succeeded in operating a train with 140 km/h of maximum speed (maximum route speed 150 km/h, scheduled speed 107 km/h) on the Gyeongbu Line in 1985, so it took approximately 4 hours and 10 minutes to travel between Seoul and Busan. Research and technology accumulated for speed improvement of the existing railway such as Gyeongbu Line made a great contribution to the HSR construction in the future.

KNR, in charge of Korean railways, internally started to review the HSR construction plan. In fact, KNR first developed the Gyeongbu HSR Construction Plan with the experts for each sector in 1971. Since then KNR also prepared an HSR Plan for Gyeongbu Line between Seoul and Daejeon in the 1st Land Development Master Plan (1972-1981) (Ministry of Construction) published in December of the same year, incorporated into the long-term plan. Additionally the SinGyeongbu Line (200 km/h HSR) Construction Plan was included in the Basic Plan for Railway Operation (1974-1981) written by KNR in December 1973. In June 1974, KNR made a request to SNCF and Research Group of Japanese Overseas Railway Technology Association regarding the introduction of IBRD railway loan and participated in the proposal of New Railway Construction for a Solution to Transport Issues between Seoul and Busan. In December 1976, KNR proposed SinGyeongbu Line (200 km/h) Construction in Basic Investigation Report on Capacity Reinforcement of Gyeongbu Line between Seoul and Busan. In December 1981, KNR and KRETA issued jointly Gyeongbu HSR Route Plan (Seoul-Daejeon), and KRIHS (Korea Research Institute for Human Settlements) carried out Feasibility Study for Long-term Traffic Investment and HSR between Seoul and Busan with the Louis Berger Group in November 1984.

Technical investigation into HSR feasibility was made under the control of KNR after the HSR implementation plan was determined in May 1989. The investigation was titled Technical Investigation & Basic Design for Gyeongbu HSR and was executed until February 1991. Accordingly, an alternative to the route and station location as well as the traffic demand and the economic feasibility analysis were reviewed for the first time. Additionally, the RFP for the selection of rolling stock type was drafted. Technical Investigation and Basic Design was an integrated research project in which 70 experts from 6 companies including KOTI (the Korea Transport Institute), local engineering companies and Lois Berger of U.S. participated.

At that time, KNR considered that the technical investigation project was a core task plan at the stage of HSR preparation according to the HSR Construction Plan and consequently it organized the HSR Planning Office in December 1989, with 54 KNR experts began to focus on the technical sector of the technical investigation project. The development of technology criteria such as route, station location, and construction standards were carried out by the KNR experts and private engineers from Yooshin Engineering Corporation, KRTC (Korea Railroad Technical Corporation), Daewoo Engineering, and Hyundai Precision & Industries Corporation. Most of the private engineers consisted of railway staff who had worked at KNR or engineers who were responsible for railway technology tasks at private companies. As the engineers from the Louis Berger Group were not railway experts there had limitations to supporting the HSR technology.

Considering basic technical standards according to the railway construction plan, Construction Regulation applicable to Gyeongbu HSR was established under the control of HSR Planning Office of the KNR. Korea didn't experience many difficulties in developing a construction standard plan because construction standards were internationally standardized and Korean railway standards did not vastly differ from international ones. Considering the 300 km/h plus of train speed, it was important to intensively review only the technical standards for high-speed operation. Thus, they compared and analyzed the construction standards of Japan, France and Germany which already had experience in HSR construction and operation. Therefore, Construction Regulation on Gyeongbu HSR with 350 km/h of design speed and 300 km/h of maximum operation speed was established to optimize the operation performance of high-speed trains to local geographical conditions and to conform to the technical conditions of UIC standards. It was finally approved by the Minister of Transport on December 28th, 1991. The basic objectives of the HSR construction regulation were: ① to secure technical interface with UIC and the existing foreign HSR, ② to adapt high-speed operation to local topography, ③ to construct tracks for diesel locomotive and the existing trains considering the interface with the existing railway, ④ to construct the tracks for a future direct connection with Eurasia railways such as China and North Korea, ⑤ to construct the tracks with a possibility of increasing speed depending on future HSR technology development, ⑥ to construct tracks that could interface with any rolling stock from Japan, France or Germany, ⑦ to secure technical compatibility between the rolling stock and the track to ensure that any bidder could manufacture rolling stock suitable to the above conditions by making a proposal in selecting the type of rolling stock type in the future.

Under the HSR Planning Office design criteria, construction specifications, and standard drawings, which were technical standards for the existing civil work, were prepared. The execution was carried out by 232 experts for each sector from KSSC (Korean Society of Steel Construction), KCI (Korea Concrete Institute), KGS (Korea Geotechnical Society) and KICT (Korea

CHAPTER 04

Institute of Construction Technology), led by KSCE (Korean Society of Civil Engineers). As a result, they drafted nine design criteria and construction specification and five kinds of standard drawings in 1992. A variety of technical standards required for track bed design and construction of HSR were drafted based on various technical standards regarding design and construction of the existing conventional railway. However, they reviewed and analyzed technical data on the HSR of Japan, France and Germany in which an HSR had already been in commercial service and they reflected necessary technical data selectively. In this way Korean engineers could prepare HSR technical standards on their own because they had a good knowledge throughout all areas of railway construction.

Detailed design of track bed was to prepare the detailed design documents necessary for the construction. Main objective of basic design executed in the technical investigation was to select the location of routes and stations and estimate the total construction cost based on a rough structure plan, so it was insufficient to carry out a properly detailed design. Therefore, there was a limit to implementing a basic design considering all conditions such as the project period, the number of engineers involved and service fees as the existing basic plan and basic design were integrated. In particular, it seemed that it was impossible to carry out a basic design at a normal level because there were many discussions and approval procedures according to the project schedule. In 1991, at the stage of detailed design, it took significant time to arrange and develop the basic technical matters to be proposed in the basic design from the beginning of commencement. First, it was because only two companies among 14 secured experts and also there was a lack of middle grade working-level engineers. Secondly, the service fee was unprecedentedly high and the companies were subjected to pressure because they were not considered as a competent company in the service industries if they lacked HSR technology. Lastly, the project volume was too huge to keep pace with the government's schedule. Meanwhile, the HSR Planning Office organized in KNR in 1989 wanted to guarantee the continuity of work with the start of Korea High-speed Rail Construction Authority in 1991. The Act on Korea

High-speed Rail Construction Authority was published on December 27th, 1991, and thus, it was possible to mobilize project implementation staff who could manage and supervise the detailed design properly according to the service establishment registration and a fresh start of KHSRCA with 379 employees. Design control personnel consisted of engineers who had experience in the design, construction and maintenance of conventional railways in KNR. Also, unskilled engineers were gradually trained to act as middle grade engineers in the process of main project implementation.

3. Securing HSR Track Bed Design Technology

The strategy for securing HSR track bed design technology was to establish construction regulations and design criteria of the Korean HSR and then reflect them in the track bed design by deeply reviewing the technical standards of the countries which had constructed and operate a HSR. Unfortunately Korea didn't have sufficient time for a technical investigation and basic design and couldn't secure technical reliability at a level of commercialization through in-depth review and technical advice on HSR of advanced countries. So the direction of design was decided to review technical reliability of the HSR technology and verify technology for the detailed design carried out by Korean engineers. Foreign experts concerned made technical review for some design criteria such as bridge and tunnel, which was considered to be sensitive technical impact on the high-speed train operation. When it comes to detailed designs carried out by local companies, it was decided to allow HSR engineers of the donor (e.g., rolling stock) to participate in reviewing the design if key technology suppliers such as rolling stock were selected.

Bridge design was the most sensitive part in the track bed detailed design for the Gyeongbu HSR. When the detailed track bed design began for the first time in 1991, the bridge section was 123.6 km of the total 421.7 km of the HSR line, accounting for 29% of total line length. Bridge among the

HSR track bed facilities had sensitive impact on the train safe operation and ride comfort on the high-speed track and the construction cost was estimated higher than earthworks or tunnels. Therefore, we examined the bridge types mainly used in France and Germany in order to choose the bridge structure type which was structurally safe and was reasonable for initial construction and maintenance. PSC-BOX structure type of 40 m span[3] was proved to be structurally stable for high-speed trains and the span with a length of 40 m was favorable from the economic aspect, so PSC-BOX structure with the length of 40 m was selected as standard bride type. However, standard bridge type of the track bed was changed in the process of reviewing the overall construction plan including route in order to cut down the project cost. A review was conducted to change the bridge type from PSC-BOX with 40 m span to PC-BEAM structure with 25 m, and the preliminary bridge design was carried out. Safety review was required to manage both design and construction strictly because deflection and bending moment of the superstructure are generally increased due to resonance phenomena[4] occurring on the deck of HSR bridges resulting in negative effects for the safety and durability of the structure. We reviewed not only PC-BEAM structure which was selected initially but also PSC-BOX structure selected through the change of standard bridge type. The result of dynamic stability review on the resonance phenomena occurred on a bridge revealed that the bridge would be safe if the height of beams was adjusted from 2.0 m to 2.5 m and the depth of deck from 20 cm to 30 cm. Dynamic stability review on the bridge resonance phenomena was carried out by an American International Civil Engineering Consultant as the main contractor and Dr. Penzien, a professor of UC Berkeley as a responsible engineer (Dec. 18th, 1993-Jun.

3) Distance between the piers of bridge. The location of span in bridge design is one of conditions to decide the type of bridge structure. It depends on the structural material, but the maximum limit of span length is 200 m for girder bridges with high tensile steel (tensile strength approx. 80kgf/mm^2), 500 m for truss bridge and arch bridges, 700 m for cable-stayed bridges, and approx. 2,000 m for suspension bridges (Source: Railway Unabridged Dictionary 2007).

4) It refers to a phenomenon where a big vibration is generated due to slight force when natural frequency of a vibrator is forced by the same frequency (Illustrated Mechanical Terminology Dictionary, 1990).

1995). As above, the bridge design for the Gyeongbu HSR was completed by Korean engineers according to the modified and supplemented design standard and then these same engineers applied the standard of 200 km/h or higher design speed of conventional railways and the bridge design for the Honam HSR.

In general, inner section area of tunnel is affected by air- pressure change of the tunnel which occurs due to train running at a high-speed of over 200 km/ in the tunnel. The sudden impact of air-pressure is due to trains running at a high-speed which can lead to tinnitus[5] due to the sudden difference in air-pressure of the train, depending on the seal. It is expected that the tunnel structure would be damaged because noise from rolling stock flows into the passenger room, wind pressure occurs when trains on the up-track and down-track cross, and repeated stress occurs due to air-pressure change. If the compressed air-pressure is diffused rapidly at the entrance and exit of a tunnel, air pressure and micro pressure such as wind pressure and plosive sound can occur. Such problems could be solved depending on the size of rolling stock, the sealing level, and the comfortability, so an optimum cross sectional tunnel area should be decided after engineering reviewing and economic feasibility. The impact of air pressure depends on the length of tunnel, the distance between tunnels and the tunnel gradient. When it comes to design criteria, the criteria of the maximum variation of air pressure in the tunnel as well as the allowable criteria of air pressure variation in the train was decided by investigating related overseas cases (US, UK, Japan, Germany, etc.). For 350 km/h train speed a cross-sectional area of double track tunnel was determined to be 107 m^2. The criteria referred to German ICE rolling stock data which was comparatively easy to obtain as the rolling stock specification and features for the analysis of tunnel air pressure because the type of rolling stock was not decided yet.

Detailed design verification was carried out to secure technical reliability

5) It refers to a kind of ringing in the ears that a person would hear even though there is no acoustic stimulation from outside (Industry Safety Unabridged Dictionary).

of track bed design using domestic and foreign engineers' technical information and comprehensively review the stability and technical interface between the rolling stock and core system. It was necessarily required to verify the track bed design executed by local engineers in order to respond to public opinion about opposition to or worrying about the HSR. After the rolling stock and core system supplier was selected as France TGV in June 1994, SNCF Systra was appointed as a technical review expert to verify the results of detailed design. The 1st design verification was intended for the track bed design of test track (1994-1995), and the 2nd design verification was for the track bed design with exception to the test track, as well as the track and construction design for the entire section (1996-1998). Major technical details of design verification are described in Table 4.2.

Table 4.2 Technical details of detailed design verification

• Review technology for the overall HSR design criteria and review technical interface between rolling stock and core system
• Review the route design standard and the details of alignment design
• Review each station design and the line arrangement standard like high-speed train nonstop stations (Cheonan, Osong)
• Review the bridge detail design standard and the aspects of detail design (axial force of CWR)
• Prepare detailed drawings of PC-BOX bridges (15 types)
• Review and supplement the specification of track bed construction, prepare the maintenance guidelines
• Support track design technology
• Support building design technology

At that time, Korea understood and learned detailed technology from the French engineers and both French engineers and Korean engineers jointly reviewed technical standards and design documents of each sector according to the category. As a result, Korea could adapt such technology to the local environment. This was a technical background that could be worked on for Honam and Seoul metropolitan HSR design with domestic technology in the future.

4. Supervision of Track Bed Construction

Track bed should be perfectly constructed to ensure high-quality track conditions as well as the safe operation of high-speed trains according to the HSR Construction Specification. An optimum construction supervision method was reviewed from multilateral aspects because it was more important to thoroughly supervise the construction site at a certain level as well as the design result. When the construction of test track between Cheonan and Daejeon commenced, the outsourced construction supervision system was not widely settled. Therefore, public agencies such as the client directly supervised the most of railway and road constructions. For this reason, the track bed construction of test track (Cheonan - Daejeon 34.4 km) was directly supervised by the employees of the KHSRCA at the beginning of construction. However, when defective construction was found on Gunghyeon Tunnel (950 m long) located between Osong and Daejeon in 1993, a negative view toward HSR construction and a distrustful public opinion on HSR technologies increasingly became worse. As a measure against defective construction, the KHSRCA decided to completely demolish the tunnel and replaced the related supervisors and concerned contractors before restarting construction. It was intended to establish the principle that defective construction was not allowed in HSR construction. Additionally it was decided to commit construction supervision to the professional supervisors and intensively reviewed the type of supervisor, either local company or foreign company. According to the change of supervision system, German DEC engineers were additionally dispatched on the test track as joint supervisors. Consequently, the overall procedure for construction supervision could be upgraded to international levels after foreign engineers including DEC were involved in the construction supervision of the HSR project. Especially, it made a great contribution to the conscious reform of strictly obeying related rules and criteria, giving Korea an opportunity to establish an ISO 9001-based quality management system, defined by the ISO (International Organization for Standardization) in HSR construction. A fully responsible supervision system was adopted in Korea for the first time.

To establish the new direction of the HSR project, an overall review was made on the status of construction quality control and safety inspections were executed in order to establish a valid quality management system. Namely, an overall safety inspection was decided on to discover the actual quality management conditions of all structures constructed between 1992 to 1996. WJE[6] (Wiss, Janney, Elstner Associates, Inc.), the American professional company for safety inspection, carried out the safety inspection for Section 2-1 between Seoul and Cheonan and for 1,012 locations covering all 61 km of test tracks. This safety inspection was divided into two steps, the 1st inspection (1996-1997) and the 2nd inspection (1997-1998). The total length of inspection section was 61.0 km; 37 places on bridges spanning 32.5 km, 15 places in tunnels over 14.7 km, and 72 earthwork location and 18 culverts on the 13.8 km earthwork section. The inspection result showed that 39 places (3.9%) of 1,012 places in total required supplementary measures such as partial reconstruction for future maintenance. According to the maintenance specification criteria proposed by WJE, the contractor proposed a repair work plan, the foreign supervisor made a review of the plan, and the repair work was implemented with the KHSRCA's approval. Repair work was incorporated in the existing structure thereby ensuring original performance would be structurally suitable to the technical standard. These checkpoints were attributed to the negligence of construction management rather than technical problems. Consequently a new quality control system was established covering construction technology support, reinforcement of supervision system, site inspection for construction safety and quality control in order to prevent defective construction.

5. Conclusion

It seems Korea had no system to utilize experience and technology abilities

6) WJE is an international safety inspection company established in 1956.

in the early 1990s despite experience in railway construction, operation over 90 years and possessed approximately 30,000 engineers. Before starting the project in earnest, Korea didn't voluntarily make preliminary preparations such as collecting technical data from advanced countries that had constructed and operate a HSR, visit sites, or training. In addition, it was too short a period of time to persuade national consensus including politicians by reviewing and establishing the project feasibility and plan. At the stage of technical investigation and basic design, it was necessary to select the type of application technology, propose detailed application technologies for each sector, and prepare detailed technical criteria, but unfortunately such a process was not carried out smoothly. To sum up, Korea didn't prepare for the HSR technology ahead of time, and as such couldn't sufficiently persuade the interested parties due to a hurried work process after the project was initiated, and the country lacked preliminary preparations for essential HSR technologies.

CHAPTER 5

High-speed Railway Track

1. Background

It is difficult to say that Korea had high-level technology for track before adopting HSR. One reason was the civil engineering departments of universities in Korea focused only on general civil engineering work such as road and no university had opened a railway-related course. At the stage of preparing the HSR construction, Korean domestic track technology lagged far behind advanced countries, which was another difficulty. Nevertheless, track was excluded from the selection of a core system and as such it was not transferred from France. Therefore we had to combine our own technology with technical advice from advanced countries in the arena of HSR.

Korea closely investigated and reviewed the track structure appropriate for HSR and construction features in advance. The features of HSR track were investigated at the stage of preparation (1989-1991) found that track material should have enough strength to bear the impact and vibration caused by HSR operation. The way to solve such a problem was to carry out construction with high accuracy and uniform quality. To intensively complete the work within a short schedule, Korea had to mobilize additional professional organizations and competent personnel because the nation needed to make a sufficient preliminary plan and preparations. For the purpose of technical advice, on the other hand, international track experts were invited from advanced railway countries such as France and Holland so as to make up for insufficient domestic technology and experience. Korea also had a technology interchange with experts from related engineering companies as well as KNR and Seoul Metropolitan Subway Corporation.

2. Selection of Track Structure and Basic Design

Prior to selecting the first HSR track structure to be constructed in Korea, HSR track data was collected and analyzed from foreign countries. We made an intensive review on HSR track conditions such as track strength, maintenance, ride comfort, and environmental protection (noise and vibration). Afterwards six track structure models were selected and installed a test track at Bugok Station (currently renamed Uiwang Station) on the Gyeongbu Line in order to carry out measurement and analysis through the wheelset drop test. From 1991 to 1994 Dr. Sato from Japan was involved in analysis of dynamic characteristics depending on high-speed train operation. At that time, Korea selected a total of six models in the process of track test with a length of 5 meters.

Table 5.1 Track test details

Classification	Rail fastening[7]	Length of sleeper	Rail pad	Thickness of ballast[8]	track bed
Test item	Pandrol Nabla Vossloh	2.4 m (existing railway sleeper) 2.6 & 2.8 m (maximum length of foreign sleeper)	10 mm rubber pad 5 mm EVA pad	35 cm 30 cm	Reinforced track bed Normal track bed

Dr. Esveld from Holland participated in the stress calculation of each track section during the same period. He also carried out the track structure's dynamic design, the review of track management limit and track bed strength,

7) It refers to rail fastening which is used to fix the right and left rails to the sleeper, concrete ballast and slab track. The right and left rails are firmly fastened to the sleeper to maintain a fixed gauge and transmit train load to the lower sleeper and ballast (Source: Civil Work Dictionary)

8) It generally refers to the thickness of track bed below the sleeper (or tie) on the ballast track, and it depends on the route standard. Usually, the thickness of the existing line is 150-250 mm, and the high-speed train is more than 300mm. (Source: Railway Unabridged Dictionary)

and the estimation of track maintenance cost so as to select an optimum alternative to high-speed operation.

At the stage of basic design for slab track to be installed in tunnels with the length of 5 km, a basic design was completed via design drawings through the feasibility study (economic feasibility and technical evaluation) by Dr. Round from the British Railway Research Institute and the structural analysis by Dr. Sato. Like a ballast track, four types of slab track with slab mats (using 25 mm micro cell mat and 25 mm EDPM mat) and two types of conventional slab track (using rubber pad and EEVA pad with a thickness of 10 mm and 5 mm, respectively) were installed at Bugok Station for the purpose of various tests and measurements. The results were incorporated into the basic design and specification.

A mix design for cement, asphalt and mortar as a filling material, was created with technical consultation from Japan. Therefore some material was imported from Japan and mixed with homemade material at the site. Other engineers, including Japanese engineer and advisor Mr. Harada, carried out a material test and verified constructability and long-term performance by injecting it on the slab track and stress testing it.

3. Preparation of Construction Specification and Track Material Design

HSR track work specification was developed considering that track work could be carried out efficiently and accurately with the state-of-the-art mechanization method. In this regard, engineers reviewed various data applicable to HSR construction adopted in advanced countries. Based on that, leaders drafted the Track Structure Standard, Track Construction Standard Specification, Slab Track Design Standard Specification, Track Slab Manufacturing Specification, Slab Track Construction Standard Specification, Rail Welding Construction Standard Specification, PC Sleeper Design Specification, and PC Sleeper Manufacturing Specification (1991-1994), which are still used as track work standards in Korea.

Unlike the existing conventional railways, track materials used for the HSR construction require strict standards and thorough quality. In this regard, the HSR of advanced countries defines the specification of track material based on continuous R&D, repetitive testing and operation experience. Korea High-speed Rail Construction Authority (1992-2003) responsible for the HSR construction technology, designed and standardized major track materials which could be manufactured and procured locally in Korea, and then carried out a design performance test to verify the conformity of quality level. Generally, design and standardization of HSR track material were carried out in order of design load → function and specification review → structure and material selection → structural analysis (stress testing each part) → performance verification test → site installation test → standardization, and so forth.

At the stage of track material design (1993-1995), stress tests were conducted on cross sections of rail (UIC, JIS, AREA etc.), based on dynamic characteristic results of high-speed trains. PC sleepers (2.6 meters long) were designed by KSCE and Seoul National University Team (preparation of structure calculation and drawing, etc.), engineers reviewed ballast bed stress, grain size and properties (UIC, JRS, AREA, CEN etc.) of ballast track, and a technical review on stress and dynamic characteristics of rail fastening was conducted. The HSR rail was specified in the track structure standard to ensure that a CWR could be adopted as 60 kg/m of rail. As the cross section shape of rail had an effect on stability and wheel abrasion characteristics while a train ran at a high-speed, the shape of rail head in direct contact with the wheel was UIC 60, and rail base was KS 60, considering the compatibility with the existing railway. However, UIC 60 was finally applied to the full rail system.

Generally, turnout is installed on the track to switch a train or rolling stock from one track to another track and it is the most vulnerable in terms of track structure. In designing a turnout and developing a standard drawing, optimized HSR turnouts including movable nose crossing and elastic points were designed with technical advice of worldwide turnout expert Holzinger from and French engineers (1992-1994), considering that a turnout is a very important factor for safe operation and ride comfort of high-speed trains. Crossing, which is the most vulnerable among the turnout, was designed as a movable nose crossing without a connection part in order to run smoothly and reduce impacts, all joints were welded, and CWR was adopted like conventional track. Incidence angle of tongue rail was eliminated, and radius curvature of the lead part was enlarged. Additionally, cant deficiency was 70-100 mm to secure more comfortable rides. Rail gradient was 1/20 and PC sleepers were used as turnout sleeper for the first time in Korea. Turnouts were equipped with mechanical double locking device, and equipped with heating devices to prevent the accumulation of snow or freezing in the winter season. For 18.5# turnout (90 km/h, approx. 68 m length) and 26# turnout (130 km/h, approx. 92 m length) with low passing speed on the branch track, the circle curve (radius of 1,200 m, 2,500 m, each) was applied to the whole turnout including crossing. For 46# turnout (170 km/h, approx. 154 m long) with high passing speed on the branch track, the circle curve (radius 3,550 m) and double clothoid transition curve were applied.

UIC 60 rail expansion joint consists of expansion parts (consisting of tongue rail and moving rail) with a length of 12.7 meters on both sides, conventional track with a length of 25 meters in the center, and its full length of 50.4 meters and tolerable stroke on one side is 300 mm. Like turnout, expansion joint also uses PC sleeper. SOFERERAIL drafted technical standards and the quality standards for major track materials such as rail, sleeper, locking device, track gravel and turnout to apply to Korean HSR, based on French, UIC, and CEN HSR standards. Each standard was confirmed through deliberation with the International Track Advisory Council consisting of worldwide track experts (December 1994), and some contents were modified during the above process.

As aforementioned, the companies concerned were notified by public announcement of the drafted technical standards and quality standards to ensure that they could make preparations in advance (October 1995). Since then, visits were paid to railway-related material test laboratories in foreign countries such as France, Holland and the UK, collecting data related to material tests and testing equipment. For track materials produced in Korea according to new standards, Korea requested the Material Test Laboratory of SNCF for a testing (20 items including vibration and fatigue) of homemade prototypes (rail fastening and sleeper). Based on the test result, the design criteria was supplemented and modified with some redesigned to complete the preparation of material standards (1995).

4. Inspection of Material Manufacturing & Production

To supply track material suitable for the new technical standards and quality standards at an international level, existing outdated domestic manufacturing facilities required vast improvement. Additionally, a material test was required to judge the conformity and quality level of track material used for track construction in the future and a severe quality control was needed for ISO 9000. Consequently, the manufacturing facilities of relevant companies were improved (1995-1996) and production facilities was investigated in advance before KHSRCA procured materials (1996-1997). Korea referred to UIC and CEN for testing methods, quality inspection details, and tolerance levels.

KHSRCA made a request to domestic and foreign experts for preparing the type of equipment necessary for manufacturing and the criteria of preliminary investigation by referring to the facilities of French HSR. Next, it organized a preliminary review & evaluation team for the manufacturing facilities, consisting of three to five domestic and foreign experts by major track material. Foreign experts comprised French railway engineers regarding the preparation of the HSR track material specification and TGV rolling stock. A preliminary review on manufacturing facilities was classified into two parts; the preliminary review (1996) and main review (1997). As most of facilities for track material manufacturing were newly imported from foreign countries, a preliminary review was performed by foreign facility experts so as to carry out checks and instruction prior to the main review. 22 kinds of machines, including a universal material tester, were introduced for testing and investigating track material (1996). As a result, the Track Department provided a location for Quality Safety Office and Quality Test Laboratory of the KHSRCA as well as Research & Test Building at Osong Track Yard, which is described hereunder. KHSRCA initiatively pushed ahead with the introduction and improvement of manufacturing facilities for HSR track material as well as enhancing quality levels according to the technical standards, it also had an influence on KNR so that the quality level of track material manufactured locally in Korea was upgraded.

For HSR concrete sleepers, KHSRCA made a pre-qualification for manufacturers who were equipped with new manufacturing facilities to conform to the design, manufacturing and quality standards before they were registered with KHSRCA and then invited them to a competitive bid. The bid was made in order of the notice on specification and facilities standards → manufacturing facility installation → application for registration → pre-qualification → bidding. KHSRCA made a pre-qualification for those with manufacturer facilities for concrete sleepers to be in compliance with the Technical Specification and Quality Standards required by KHSRCA, and who prepared a Quality Assurance Plan according to the Quality Standards required by the KHSRCA, and who applied for a bid. KHSRCA granted qualified manufacturers for the bid.

When track material specifications were developed, the annual capacity of manufacturing rail for the existing railway and subway was approximately 137,500 tons involving two manufacturers. However, it was more demanding to secure the rail quality appropriate for the HSR rail because there was a discrepancy in the cross section shape and material specification between the existing KS rail and UIC HSR rail. Accordingly, KHSRCA made a preliminary review on the conformity of the manufacturer's facilities and quality assurance plan, and the qualified bidders were invited to an appointed competitive bid. The bid process was as follows: decision of specification and cross section shape → notification of specification to manufactures → installation of manufacturing facilities → preliminary review of manufacturing facilities → main review of manufacturing facilities → bidding. The pre-qualification was carried out in a way similar to the concrete sleeper.

Track gravel for the HSR should maintain a prescribed strength to disperse the impact and load of a high-speed train while transmitting it to the track bed. Track gravel should also have a low wear rate to keep the alignment as long as possible. Therefore, Korea decided the modified track gravel specification for HSR would be reinforced more than the conventional railway specification. Korea initially used rubble from tunnel excavations as track gravel, but after continuous lithic analysis it wasn't adopted as the tunnel rubble didn't even reach the specification of French conventional railway. According to the appointed competitive bid, Korea procured track gravel from suppliers whose products passed the quality standards of physical properties. The process was as follows: notification of lithic analysis request for suppliers who wanted to produce track gravel for the HSR → receipt of lithic analysis application form → sampling and quality test (domestic and foreign) → notification of lithic analysis result → bid presentation → bidding. Nationwide 49 companies surveyed quarries for track gravel and submitted multiple samples and quality tests; however, there were only two quarries suitable for HSR.

With existing railway turnouts, the Daejeon Maintenance Depot and one private company manufactured low-speed turnouts and supplied them to subways according to private contract. Nevertheless, the manufacturing facilities and technology level lagged, so it was necessary to improve the facilities and adopt technology in order to produce high-speed turnouts. To select an adequate turnout manufacturer, the nation turned to a private capital inducement company through two public invitations printed in newspapers, and then factories were built to manufacture and supply high-speed turnouts. The process was as follows: notification of a request for high-speed turnout manufacturer → technical proposal receipt → manufacturer selection → manufacturing facility review → contract. For pre-qualification, the existing facilities were complemented so that the design, manufacturing and quality standards of high-speed turnout could conform to the requirements of the KHSRCA. The state-of-the art facilities were pre-screened in order to manufacture high-quality turnouts. Turnout manufacturer was appointed in 1993, with the factory completed at Osong Rail Yard in 1996, and main review was carried out through the commissioning at the factory.

5. Construction Experience

Track gravel for the HSR was washed off to reduce dust before use according to specifications, but plenty of dust occurred during gravel work in tunnels causing many difficulties. Thus, the contractor provided gas masks for the persons concerned. Those who worked for transport industries such as a freight car driver for track material and transportation controller complained much more than the track construction workers. According to foreign HSR, after completing track work the inside of the tunnel would be rinsed by the cleaning equipment to wash dust out of the tunnel. This work was carried out by moving a water tank freight car (2 cars per train set), equipped with water tank, sprinkling system on the track surface, and sprinkler system for the tunnel lining.

In the high-speed turnout section, drivers from conventional railway and equipment operators (e.g., motor car, etc.) kept only a conventional fixed crossing in mind. They had to pass only when the tongue rail of a point machine and the movable nose rail of a crossing were in the same route at the same time. Nevertheless, they often only checked that the tongue rail was activated, without checking the crossing state, and tried to pass through the turnout while the movable nose rail of the crossing wasn't activated. This led to frequent damage of the nose rail occurring from the track construction on the test track. In this regard, drivers or equipment operators should be trained for the difference between a high-speed turnout and a conventional turnout.

6. Verification of Completed Structures and Use of Tracks

For the completed track section, a validity verification team including foreign track experts was created in order to verify track performance. As a result, it was evaluated that the tracks of Korean HSR were very excellent and were comparable with those of foreign countries. KHSRCA internally executed a general verification procedure for completed structures as follows: to verify the safety required for KTX train running, train speed started at 60 km/h, then increased to 120 km/h, 170 km/h, 230 km/h, 270 km/h and 300 km/h (6 steps). Track conditions were observed, horizontal and vertical vibration acceleration was measured for both car body and bogie, and also inspected the track alignment with an inspection car after the train running. Data was measures and analyzed each time the train sped up and if any problem occurred it was solved before retesting.

KTX trial runs were continuously carried out on the test track (1999-2003) noticing the train wobbled severely in cold weather. In May 2003, it was concluded that the core contractor should install an extra transverse damper and advisable changing the wheel grade from 1/40 to 1/20 in order to solve such a train shaking problem through various investigations, tests and review.

To prevent gravel from flying when a train was running at a high-speed, or from flying gravel due to falling pieces of ice formed on the underside of rolling stock during heavy snow in winter, we adopted the most economic and efficient method (upper side of track gravel was 5 cm lower than upper side of sleeper) discovered through case studies of foreign countries like France, Germany, and Japan. This method was recommended by French engineers and passed through the review of International Advisory Council on Tracks (May 1999). When a KTX train was running a trial test on the section which adopted the above method, some micro particles of track gravel flew causing damage to rail and wheel treads, and it was considered to be one of many causes of wheel damage. The Track Department made efforts to reduce the above phenomena by securing a prescribed track bed section and cleaning up thoroughly after ballast repair work.

In the case of snow in winter, unlike the existing track, snow on the track was picked up by train winds due to high-speeds. The now then stuck to the under frame of rolling stock, gradually grew and then refroze forming a lump of ice. After the train passed through snowy sections, the lump of ice would drop down and collide with the track gravel. Due to the impact, ice and the track gravel would bounce causing damage to the under frame of rolling stock. In December 2003 KNR, as an HSR operator, established the rule that high-speed trains must travel slowly at 230 km/h or 170 km/h when traveling through heavy snow. Even if it doesn't snow on an HSR track, it is likely that when KTX is running on a snowy section of existing track, such as Honam Line, a lump of ice can form on the underside of rolling stock sometimes and later drop onto the high-speed track. Thus, it is required to check and remove ice on the underside of rolling stock when KTX vehicles move in or out of the depot. The Track Department continues to take measures to prevent gravel from flying.

7. Conclusion

As aforementioned, the HSR track work passed through design consulting and verification, project management consulting, and construction consulting and verification during construction. Korea took advice on major HSR track technologies through consultants from the International Advisory Council on Track (international track experts including Mr. Montane from France, Mr. Kaess from Germany, Dr. Sato from Japan, Dr. Esveld from Holland, and Prof. Reissberger from Austria) which have been hosted by KHSRCA over ten years. Major technical matters reviewed and planned by the KHSRCA have been certified. Korea accumulated track technology through the exchange of cutting-edge technology information and initiatively upgraded local railway technology. During the project, we furthermore made an innovative attempt at constructing a track without using wooden sleepers on all the tracks; a world first.

As above, the nation systematically made preparations for HSR construction. That is, Korea constructed a test track decided on a unique track structure through various tests and measurements and upgraded all material manufacturing facilities to an international level. Although receiving technical assistance from advanced overseas countries, Korea has determined that the track is one single part among HSR project activities in that local railway technology has been upgraded further and tracks have been constructed at an international level with domestic efforts and technologies.

CHAPTER 6

Operation Technology

1. Overview

KNR, which has been in charge of Korean railway operation for over 100 years, gave control of the construction sector to the Korea High-speed Rail Construction Authority, organized the HSR Operation Task Force to make preparations for opening the HSR by November 1994, established a master plan for HSR operation preparations, and proceeded with the task on a step-by-step basis according to the construction schedule. The preparation for the HSR operation was categorized into seven steps; organization of a task force, manpower training, setup of an operation system, establishment of a sales strategy, setup a commissioning plan, and preparations for both maintenance and opening. Afterwards, it was subdivided into 25 unit tasks to ensure that the responsible staff could concentrate their capabilities on the required task. Tasks were on the basis of at least 1,000 WBS (work breakdown structure) based on process control.

The preparation for the HSR operation was categorized into three steps. The first step (November 1994 - December 2001) referred to 'a basic design setup and pre-operation,' so a basic design was established for the acceptance and operation of high-speed rolling stock, and basic preparations were made. During the 1st stage, high quality personnel with years of experience in the existing railway were selected by instructors for language training and technology transfer of the new system as the core contract with France was centered on rolling stock. Meanwhile, the organization for preparing HSR operation was improved and mainly focused on checking the progress status of test track and segment construction in connection with the train operation. The 2nd step (January 2000 - October 2003) referred to 'a setup of operation system and commissioning.' Trained staff was deployed to sites, the operating organization was expanded and re-structured, and a variety of operation systems and rules were improved. At the same time, a fare system, marketing strategy, and practical preparations were established. Lastly, the 3rd step (January – April 2004) referred to 'an integrated commissioning and final inspection,' and Korea finally inspected the train operation plan, facilities and equipment. Furthermore, preparations were made for opening and commencing commercial service and a trial run through the entire segment was carried out for about three months after the integrated commissioning (Seoul - Busan, Seoul - Mokpo) was completed. During the trial run, a train operation simulation test was carried out, the status of passenger handling was inspected, and station convenient facilities and passenger circulation checked.

2. Training and Operation Support Program

From the beginning, KNR operated a training program for HSR operation staff on a step-by-step basis. First high quality personnel, such as instructors and managers, were selected and dispatched to France in order to take over the cutting-edge maintenance technology and operation know-how from TGV. At the same time, KNR organized a task force for HSR in each technology department of KNR and began to train the most intragal operation staff. KNR selected excellent instructors from each sector through language exams and sent them to the Language Training Institute of Hankuk University of Foreign Studies (HUFS) to improve their language skills and then dispatched them to start long-term training according to the agreement with the French SNCF-International. Overseas training began with manager and instructor training (37 persons in 1996 and 22 persons in 1997) and the total number of trainees amounted to 450 personal including 50 individuals for a manager course, 73 for an instructor course (KNR: 58, the KHSRCA: 15) and 300 personal for a working level staff. After coming back to Korea, they trained 4,000 local staff and simultaneously carried out an OJT on the test track section for a rolling stock acceptance at Osong, Chungbuk Province. Additionally, KNR has started making an intensive investment in practice equipment and materials as well as a practice workshop for efficient training since 2001.

Table 6.1 **Budget investment in KNR Management Training Institute for KTX opening**

(Unit: million KRW)

Total	2001	2002	2003	2004
10,570	3,585	1,985	2,000	3,000

Table 6.2 **Annual status of budget investment in KTX Training Institute for rolling stock**

(Unit: million KRW)

Year	2001	2002	2003	2004
Contents	Air brake (1,002)	Brake (347) Auxiliary (177) Control (100) Safety (174) On-board computer (74)	Car body (160) Mechanical (290)	Air pressure and electricity (490)

KNR developed a variety of training equipment and materials as well as an operation support system at the stage of the HSR operation preparations.

Table 6.3 **Summary of cutting-edge equipment & materials developed during the HSR operation preparations**

Equipment & materials	Area	Application area
CAI, driving simulator	Driving	Virtual training, brake practice
IRIS	General information	Integrated railway information network
MICS	Maintenance	Inspection plan using communication technology
KTX OIS	Train operation information	Train plan and control
RCM	Safety control	Reliability-centered maintenance

Practice equipment was installed and materials provided for training the HSR maintenance staff. CAI (Computer Aided Instruction) teaching aids were developed using cutting-edge technology and a new training system

Figure 6.1 Computer-aided instruction

was developed for virtual training from 2002. Furthermore, an operation simulation system for the crew was installed separately.

Before the HSR commercial service was launched, a plan for users and system operators was established in order to smoothly operate the IRIS (Integrated Railway Information System); the core operation system. Furthermore, professional operator training was carried out for system maintenance so as to train professional staff continuously.

Table 6.4 Annual status of HSR operator training

Classification	Plan	By 1999	2000	2001	2002	2003 Sept.	Total
Foreign	414	87	58	73	104	52	374
Domestic	3,454	85	443	684	1,047	777	3,132
Total	3,868	172	501	757	1,151	829	3,506

When it comes to maintenance, MICS (Maintenance Information Control

System) was developed to support new HSR depots and efficiently manage and support maintenance work for high-speed rolling stock. With the concept of optimum inspection plan, development began on a program to optimize an inspection plan using radio communication technology in high-speed rolling stock. On top of it, KTX OIS (Operation Information System) was developed to allocate a train efficiently and transmit operation information wirelessly. Also, a unique Korean designed RCM (Reliability Centered Maintenance) system was installed at depots in order to ensure safe train operation as well as punctuality and safety by securing the maintenance reliability of the high-speed train. In addition, the KROIS of KNR and IRIS (Integrated Railway Information system) for HSR operation were developed to support the operation services as well as the maintenance of the existing rolling stock.

Table 6.5 Details of IRIS setup by step

1st Step (Dec. 2000 - Nov. 2003)	2nd Step (Jan. 2002 - Dec. 2004)
Marketing, transport plan, train operation plan, rolling stock operation plan, reserved ticketing, operation management, AFC, inspection information, commercial service management	Crew management, revenue management, customer management, capacity adjustment, sales, management information, travel products portal

3. Estimation of Manpower Required and Depot Completion

Before the KTX commercial service began, manpower required for operating the high-speed train on the electrified section of the Gyeongbu HSR and Honam Line was estimated at 2,766 personal assuming skilled experts were mobilized. Among them, 1,457 people were secured by redeploying the existing manpower according to workload adjustment of the existing railway. This figure accounted for approximately 10% of total KNR employees, which was evaluated to be higher than foreign cases like Germany and France where 5 to 6 personal/km were mobilized. At that time, the basic policy for recruiting the HSR operation staff was to select skilled and quality staff among the existing railway employees and transfer them to the new position after professional technical training

Table 6.6 Result of HSR manpower estimation

Classification	Manpower required (A)	Alternative manpower			Outsourcing (C)	Extra manpower required (A-B-C)
		Work adjustment	Persons secured	Total (B)		
HQ	118	-	180	180		-62
CTC control	52	-	-	-	11	41
Station service	445	265	2	267	148	30
Train service crew	368	251	-	251	117	-
Driving	246	103	14	117		129
Facility	360	-	45	45	106	209
Electricity	315	-	78	78	43	194
Rolling stock	862	492	27	519	214	129
Total	2,766	1,111	346	1,457	639	670

HSR depots were built in Goyang City of Gyeonggi Province and the Gaya District of Busan City and completed in 2004. Since then, the high-speed rolling stock was finally accepted.

Table 6.7 Status of high-speed rolling stock depots

Classification	Project period	Project cost	Site	Track and catenary
Goyang High-speed Rolling Stock Depot	Dec. 4th, 1998 - Dec. 30th, 2003 (58 months)	203,975,000.000 (KRW)	1,313,324 m^2	Track 34 km (32 km)
Busan High-speed Rolling Stock Depot	Jan. 11th, 2002 - Mar. 31st, 2004 (28 months)	109,260,000,000 (KRW)	370,939 m^2	Track 20.14 km (19.91 km)

4. Commissioning of High-speed Rolling Stock

Since December 1999, the KTX rolling stock manufactured by France was commissioned in order to both verify a technical correlation between the rolling stock and track and validate safety during commercial operation. On June 25th, 2000, six months after commissioning began, KTX achieved running at a speed of 300 km/h on the 34.4 km test track between Sojeong

Figure 6.2 Goyang Depot

Figure 6.3 Busan Depot

Township, Yeongi County, Chungnam Province and Hyeondo Township, Cheongwon County, Chungbuk Province, for the first time in Korea. In November 2000, the test track segment of 57.2 km in length was completed and the rolling stock acceptance test was carried out under the design demonstration test under the control of the KHSRCA. Vehicle swaying phenomena occurred during the commissioning in winter, and the wheel profile of a passenger car was finally changed from GV40 to XP55 before the rolling stocks were accepted.

Mass-produced rolling stocks manufactured locally in Korea were continuously tested according to the SAT Plan which was a dynamic & static test procedure. Some problems such as main transformer overheating were resolved in cooperation with French engineers. Commissioning was first carried out by the rolling stock manufacturer at the factory and on the operating track in France in order to minimize problems. Basic tests such as train function test were carried out as follows: For the 1st train set, general items such as traction and brake, and on-board computer were tested for 24 months, the 2nd train set for 1 month, and the 3rd train set for 4 months. In 2002, the verification test of the existing track was executed for the purpose of upgrading speed and verifying the safety during the commercial operation. At that time, commissioning was carried out to ensure that KNR, as a future operator, could possess independent test data and verify the performance of rolling stock.

Table 6.8 Verification test of KTX rolling stock on existing track

Classification	1st Commissioning	2nd Commissioning
Commissioning name	Blank Run Test	Wheel/Track Force Test
Date	January 7th ~ 9th, 2002	February 2002
Section	Yongsan - Bugok (three round trips at 60 km/h, 90 km/h, and 110 km/h)	Yongsan - Bugok 18 round trips (7~10 days taken)
Test details	Pantograph behavior, train set dynamic behavior, ATS operation monitoring, traction and braking status check, signal electro-magnetic interference, wheel tread shape measuring, distance measuring between platform and train (Siheung Station), wheel/track contact monitoring.	Wheel/Track force test, manufacturing two sets of special test bogies, and installing one set at both the power car and passenger car bogie

An integrated commissioning test was carried out for 12 train sets manufactured overseas lasting from October 2003 to December 2003 and 34 train sets locally manufactured in Korea from February 2004 to April 2004. KNR organized a joint technology team with KRRI and SNCF-I to proceed with the final rehearsal by installing equipment similar to the measuring instruments installed on G7 rolling stock. KNR performed all measurement tests according to international standards, stores all data on DVD, and published the test result in a book. Additionally, HSR construction standards were confirmed; 7,000 meter minimum curve radius, 25% maximum gradient, 14 meter formation width, 5 meter track center distance, and 107 m^2 for tunnel areas, which was the largest at that time.

HSR operation preparations were made on the assumption that the high-speed train should run at a speed of 300 km/h. The existing railway operation technology was changed from 100-150 km/h of low-medium speed to 300 km/h of high-speed with totally different features. In this regard, the country had no choice but to investigate international safety systems and maintenance systems in order to respond to various unique situations. Thus, it could be exposed to physical risks because Korea had no experience operating 200 km/h medium high-speed rolling stock. In particular, a special crane for relief operations and a remodeled diesel locomotive were separately deployed by adopting the concept of emergency stand-by vehicles. Also adopted was the concept of documented emergency management guidelines

Figure 6.4 HSR commissioning at Osong Depot

Figure 6.5 Ticketing at Seoul Station on opening day

and improved applicable rules to designate as company regulations and then mock emergency situations were simulated for thorough additional training. Furthermore, major stations on the existing line were used as they were because the original construction plan was not followed. This frequently meant trains standard trains and high-speed had to take turns. Vulnerabilities were exposed due to replacing CTC (Centralized Traffic Control System) and ATS (Automatic Train Stop System) with ATC (Automatic Train Control system) TVM43, as well as due to the crew's manual handling of neutral sections of the existing line among the many neutral sections (HSR: 13, existing line: 17) of the AC feeder section. Therefore the need of thorough complementary measures to reinforce the function of adopted rolling stock was recognized. Above all, a detector channel was installed for the neutral sections of the existing line at the ATS and cabins were equipped with homegrown GPS technology to provide assistance to the high-speed train driver. Also, we developed a pre-notice system for operating on the existing line or vulnerable sections to provide an announcement of major switch handling to prevent accidents.

According to the strict HSR construction standards, it was required to manage many tunnels (77 km, 46 locations) and bridges (84 km, 86 locations) as well as operate the track maintenance team to protect against destruction of HSR due to axial loads of 17 tons, cope with difficulties such as the elaborate HSR management standard, manage high-speed turnouts on the connecting line, and oversee the CWR setup with which domestic experience in track maintenance was lacking. Therefore, we monitored the status of track and catenary by preparing reserve turnouts, continuously used test vehicles, prevented ride comfort issues or vibration noise problems through noise and vibration tests, and furthermore we adopted an additional catenary measuring system on the track for scientific maintenance. For the operation of high-speed trains, as recently observed in global railway industries, we made every endeavor to secure running safety, including wheel abrasion, through continuous academic research on the correlation between wheels and track. The need to understand the correlation between wheels and track emerged from vehicles swaying in winter, the wheel abrasion that occurred when a train runs alternatively on the existing track and HSR, and wheel cutting cycle adjustment for equivalent conicity management. Above all, Korea changed to the XP55 wheel and adopted a solid oil sprayer. Future plans include fundamentally developing a new suspension system through the G7 rolling stock project.

Lastly, it was difficult to manage safety until the HSR was launched because night work, such as frequent switching work and blocking on the operating track, was carried out 70 to 100 times a month to improve existing track. It was also demanding to work out countermeasures and give assistance to the site managers to secure and train maintenance and operation staff. Rolling stock and facilities needed preparations for HSR service while operating the existing trains at the same time. On top of that, according to the results of tests and commissioning of the existing line from May 2003, facilities quickly needed to be completed and reinforced in order to eliminate potential problems such as train delays.

As major measuring instruments for commissioning the KTX, a traction brake measuring instrument was installed in the rolling stock as well as a video monitoring device designed to check the real time status of current collection between the catenary and the pantograph and record information such as current, voltage, train speed, distance, and the height of catenary overhead line so that such information could be accurately analyzed later.

Figure 6.6 Gwangmyeong Station under construction

Figure 6.7 Cheonan· Asan Station

Traction and brake measuring instruments, connected to the motor block and major devices, receive signals from 32 channels such as wheel axial speed, motor block output, oil temperature of the main transformer and brake cylinder pressure. As a result, the measuring instruments could analyze and store 1,000 pieces of data per second to display traction and braking capacity.

5. Final Pre-operation

The pre-operation process of the HSR was to first prepare the hardware system, that is, the adoption of rolling stock, the completion of station and track, and solve a variety of technical issues such as test and commissioning

Figure 6.8 Catenary and pantograph monitoring device

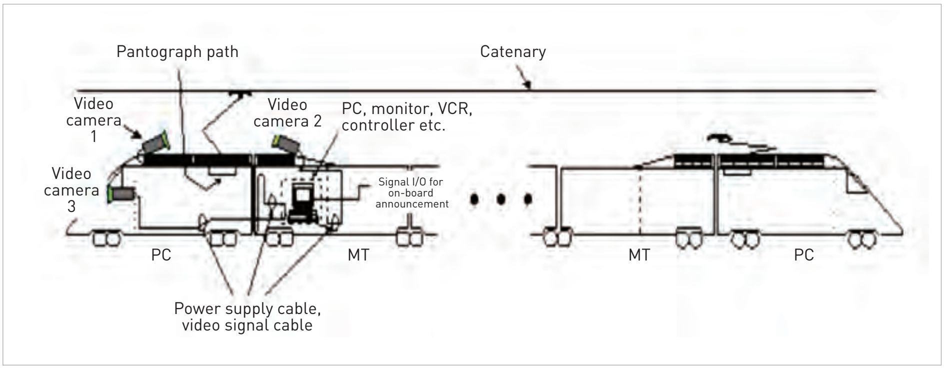


Figure 6.9 Pantograph monitor camera

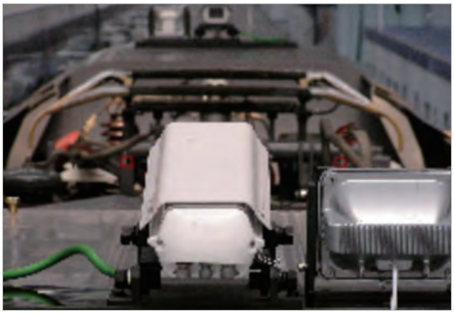
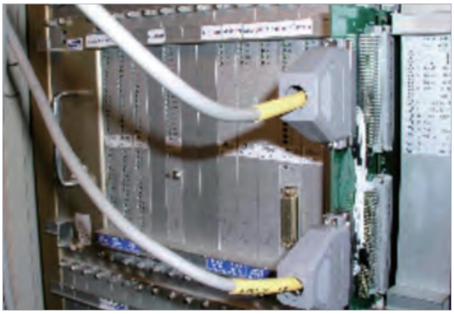


Figure 6.10 KTX motor block test connector



to put the system in an operational state. In addition to that, it was also important to train operation staff, deploy manpower and decide various systems before launching service.

In the case of Korea, it was more important to thoroughly manage safety because preparations were made for the HSR service without any experience in HSR operation. In this regard, the following preparations were made. First, the hardware system has many fail-safes in its design. So if a train set is decoupled during operation, the front and back trains are stopped automatically. The train is automatically stopped even if a driver is incapacitated. The signal to proceed doesn't work if the rail is disconnected, if voltage falls down below the baseline, power fails, or if one of many conditions are not in their normal state. Thus the signal to proceed is not displayed if safety is not assured. Second, the system is also designed to prevent an accident even if the Trans Lock System is out of order, or a person makes a mistake. To make the signal display a proceed signal when a train departs from the station, related switches must all be in their normal direction and also the conditions of related tracks or signals should not affect the train departure. If any of them don't conform to the conditions, the signal to proceed is not displayed. Namely, it is designed to make a connection between the signals, between the point machines, and between the signal and the point machine. In addition, the train departs after the signal handler, train observer, departure signer and driver check the proceed signal on the departure signal. This means that if a signal handler makes a mistake, the train observer or the departure signer first checks the proceed signal on the signal with the driver last checking it to prevent an accident. Lastly, safety system is reinforced by the principle of maximum limit. The high-speed train is also furnished with a computer to process bulk information while the ATC (Automatic Train Control) was adopted to recognize the location and speed of a proceeding train, the distance between trains and track conditions, and operation route in order to provide the optimum speed of operation train to the driver. If the driver is beyond speed limit, the speed is automatically reduced or the train is stopped. Additionally, the high-speed trains are equipped with ATESS which functions like an aircraft black, a shock absorber to minimize the impact if a train collides with another object, and the articulated bogie to assist if the train is derailed and ensuring much higher running performance and safety than the existing railway in case of derailment. In addition, safety equipment was installed on the track to detect risk factors in advance due to unexpected mechanical issues, physical danger, strange weather conditions, or natural disasters in order to ensure train safety and facility protection.

Like the safety system, driver training is very important. Excellent drivers with abundant experience were selected to take a three week theoretical education. As aforementioned, a driving simulation was used to conduct a virtual training for three weeks. With virtual training in a mock cabin under real world conditions they could improve their ability to respond to various situations. For corrective measures against failure and driving practice, 13 (16 hours or more) round trips on the existing line and 4 round trips (60 hours or more) on the HSR track were carried out to recognize the route.

Table 6.9 **Training time - total 12,263 hours/trainee**

Classification	No. of round trip train (a)	Operation hours (based on round trip)		Total (aXb)
		Base	Applied (b)	
Seoul ~ Daejeon	176	1.38 hrs	2 hrs	352 hrs
Seoul ~ Busan	1,105	5.20 hrs	6.8 hrs	7,514 hrs
Seoul ~ Mokpo	645	5.56 hrs	6.49 hrs	4,937 hrs
Total	1,926	-	-	12,263 hrs

6. Major Results

Operation efficiency demonstrated that Korea made thorough preparations for the high-speed rail. Korean HSR is operating at an international level, considering more than with punctuality and safety at over 98% which is comparable to overseas countries. It proves Korea has utilized HSR technology successfully and efficiently.

Table 6.10 Railway accident status

Country (company)	No. of accidents			Mileage (million km)	No. of accidents (million km)	2008 (million km) collision derailment
	Collision derailment	Crossing	Total			
Swiss (SBB, etc.)	2	4	6	164.981	0.036	0.038
Italy (FS)	12	5	17	307.177	0.055	0.067
Korea (KORAIL)	-	11	11	118.784	0.092	0.116
Germany (DBAG)	40	62	102	870.031	0.117	0.138
Japan (JR)	4	190	194	775.856	0.250	0.191
France (RFF/SNCF)	21	49	70	482,257	0.145	0.130
Austria (BB)	15	24	39	148.666	0.262	0.248
Belgium (SNCB/NMBS)	1	17	18	91.436	0.198	0.273
Poland (PKP)	9	99	108	172.265	0.628	0.637

Source: 2009 UIC Yearbook of World Railway Statistics

CHAPTER 7

Conclusion and Implications

Korean HSR construction can be featured as the difference between the inherent goal and established goal. It was inherently designed to substitute the maxed out the traffic demands of the Gyeongbu Line, but public attention was directed to the independency of HSR technology and the training of railway experts during construction. In the process of adopting an HSR, a test track was first constructed to test a TGV model (KTX), and Korea could have had the capability to develop a domestically designed Korean HSR with homegrown technology based on years of abundant experience in commissioning, with Korea later further paving the way for training railway experts. As stated above, such a project implementation method was internationally unprecedented, with exception to HSR-developed countries such as Japan, France and Germany, in that a test track was first built to test newly adopted rolling stocks for the performance verification and improvement. But, the above method was resolutely followed providing an opportunity to acquire the current level of HSR technology.

Visible and measureable results of HSR adoption include the development of new technology and new construction method development as well as the construction supervision system, design criteria changes and project management procedure emerged through the comparison of before and after the implementation. In addition to them, unmeasurable results include conscious reform of construction quality management, technology upgrade, confidence in HSR operation, the outcome of sales connected with IT, reservation system, ticketing system (e-ticket, SMS etc.), and a multiple charge system (weekday and weekend). Pushing into overseas railway markets is one of the HSR construction results as well. For example, Korean contractors were acknowledged as participants in the Gyeongbu HSR project and signed a contract for three sections of Taiwan's HSR project. Also Korea Rail Network Authority (KR) and local engineering companies jointly participated in supervision over some sections of China's HSR construction project and signed a contract worth billions of dollars. A strategy for extending the future business to foreign countries is to reinforce the integrated engineering function of railway industries because a railway project contract is signed on the basis of a turnkey railway system including rolling stock, construction and operation.

Korean local railway system has been established with the adoption of foreign technology or through years of experience, but the safety and reliability of the system will be an important key point as technology is gradually advanced and the professional field is subdivided. Considering that the HSR projects are recently on their way to emerging countries with poor experience in modern railway operation, the project plan and major technical standards are often determined referring to a specific country's standard or advanced railway operation cases. Accordingly, it is important that Korea should endeavor to record the experience and know-how of HSR construction and provide it to emerging countries as a success story, making them adopt our standards as major technical standards for future projects.

Lastly, one of the HSR adoption results is a high-speed upgrade for the existing line. Initially, the high-speed project for the existing line was focused on the electrification of the existing line connected to the HSR in order to extend the KTX service area. Since KTX was launched, work has proceeded with the improvement project for a high-speed operation of the existing line as well as the speed upgrade to 250 km/h on a newly constructed main line. Consequently, the economy and society have been positively affected in that every part of the country is now accessible within a half-day as the railway network has a speed of over 200 km/h.

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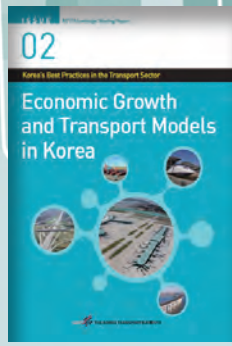

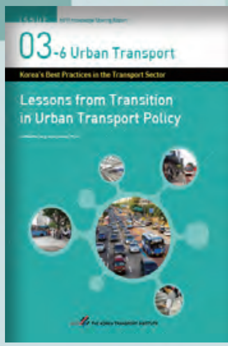

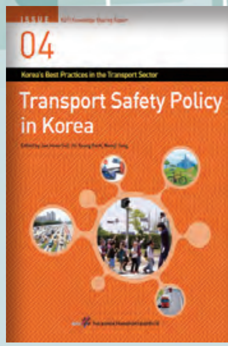

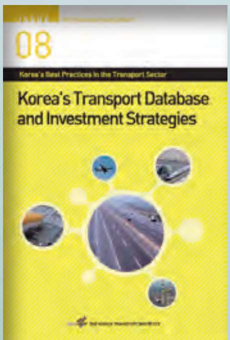

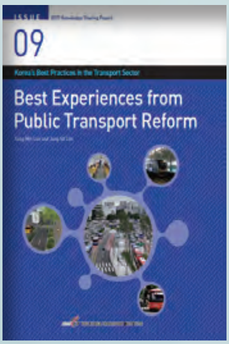

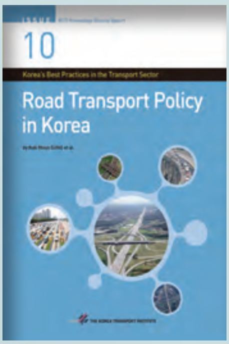

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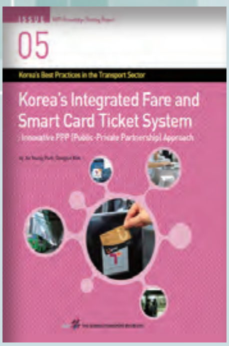

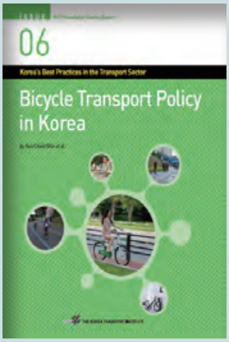

Korea's High-speed Rail Construction and Technology Advances

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