Analyzing Schedule Delay of Mega Project: Lessons Learned From Korea Train Express

Seung Heon Han, Sungmin Yun, Hyoungkwan Kim, Young Hoon Kwak, Hyung Keun Park, and Sang Hyun Lee

***Abstract*—In 2004, Korea became the fifth country in the world to own and operate a high-speed railway called Korea Train eXpress (KTX). Numerous uncertainties and challenges during planning and managing phase resulted in schedule delays and cost overruns. The delay causes of each activity along the 412 km Korea high-speed railway route were very difficult to identify because KTX project consisted of 11 141 different activities. This paper evaluates challenges, obstacles, and performances of KTX project. First, critical sections in the railway route that influenced significant delays to project completion were identified. Then, delay causes of these critical sections were investigated thoroughly. The analysis discovered five major delay causes for KTX project. They are lack of owner's abilities and strategies to manage hi-tech oriented mega project; frequent changes of routes triggered by conflicts between public agencies and growing public resistance from environmental concerns; the inappropriate project delivery system; a lack of proper scheduling tool tailored for a linear mega project; and redesign and change orders of main structures and tunnels for high-speed railway, which is fundamentally different from the traditional railway construction. Based on the in-depth analysis of KTX project, through which a conceptual framework was established to identify the various facets of mega projects, this paper suggests lessons learned for engineers to better prepare and respond to potential causes of schedule delays for mega projects.**

***Index Terms*—Delay analysis, high-speed railway, mega project, project management, schedule delays.**

I. Introduction

THE "megaprojects paradox" is well illustrated by Flyvbjerg *et al.* in their book *Mega Project and Risk: An Anatomy of Ambition* [14]. There exist strong needs for ever-increasing size of projects, such as the Channel Tunnel between U.K. and France, the Central Artery/Tunnel Project in Boston, MA, and the Oil Sands Projects in Alberta, Canada, to name a few. However, more often than not, the performances of such mega projects tend to be strikingly poor in terms of cost and time. For example, according to Flyvbjerg *et al.* [13], [15], the cost overrun happened in almost nine out of ten projects, and actual costs were, on average, 28% higher than the estimated cost. In many cases, a significant gap occurs between what is expected from the huge investment of resources and what is actually obtained from the project investment—the megaprojects paradox.

In this regard, Flyvbjerg *et al.* [14] wrote, "A main cause of overruns is a lack of realism in initial cost estimates. Contingencies are set too low, changes in project specifications and designs were not sufficiently taken into account, changes in exchange rates, and quantity and price changes are undervalued as are expropriation costs and safety and environmental demand." In short, the overoptimism of owner and project managers, the so-called delusion of success, is strongly contributed to cost and time overrun of mega projects [24].

Similarly, Korea has mega projects that suffered cost and time overruns due to the reasons that are akin to the aforementioned cases. Thus, Korean Government has tried to intensively manage total project cost and time of mega projects under the strict regulations [20]. Mega construction projects generally require large budgets and extended schedule for construction and they involve many activities and complex procedures. In Korea, mega projects are typically defined as project that is over US$ 1 billion with more than five years in durations. As summarized in Table I, the performance of most mega projects since 1990s has been poor in Korea. The average final cost at completion has been increased by 122.4% compared to the original budgeted cost and the average duration has also been extended by about 3.6 years. On the contrary, other 29 medium-sized projects with the cost of between $50 million and $1 billion during the same time span have confronted less failure with 32.5% in cost increase and 2.4 years in time extension.

Generally, the causes of delay in Korean mega projects are classified into five categories: insufficient planning; difficulties in acquiring right of way; inefficiency of project management and monitoring system; conflicts between organizations; and strong public resistance [29]. All of the direct or indirect participants tend to maintain different interests in the same project, making it extremely difficult to properly align them for project success. The sheer size and complexity of the project can easily lead to inefficiency and low productivity. Even though these causes, normally found in Korean mega projects, can be repetitive in any construction project, they tend to bring poorer results than those of smaller projects in both size and complexity.

In the pursuit of successful project performance, time control is one of the most important functions, especially in megaprojects where various risk variables cause schedule delays. Schedule delays have been a source of great distress to both owner and contractor mainly because time overruns are directly or indirectly connected with cost overruns [17]. If a mega project is

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S. H. Han, S. Yun, and H. Kim are with the Department of Civil and Environmental Engineering, Yonsei University, Seoul 120-749, Korea (e-mail: shh6018@yonsei.ac.kr; smyoon97@yonsei.ac.kr; hyoungkwan@yonsei.ac.kr).

Y. H. Kwak is with the Department of Decision Sciences, School of Business, The George Washington University, Washington, DC 20052 USA (e-mail: kwak@gwu.edu).

H. K. Park is with the Department of Civil Engineering, Chungbuk National University, Chungbuk 361-763, Korea (e-mail: parkhk@chungbuk.ac.kr).

S. H. Lee is with the Korea Rail Network Authority, Seoul 301-803, Korea (e-mail: leesh2999@yahoo.co.kr).

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TABLE I
PERFORMANCE OF RECENT MEGA-PROJECTS IN KOREA

Projects	Changes of Master Plans	Cost (Billion USD)		Completion Year		Variations Particulars	
		Before	After	Before	After	Cost Overrun (Billion USD)	Extension (Years)
KTX Project	3 times	5.8	18.4	1998	2004	▲ 12.6	▲ 5.5
B Project	4	3.4	7.5	1997	2000	▲ 4.1	▲ 3
C project	2	2.5	3.8	1996	1999	▲ 1.3	▲ 3
D Project	3	3.2	4.8	1997	2002	▲ 1.6	▲ 5
E Project	2	1.3	3.5	2001	2002	▲ 2.2	▲ 1
F Project	4	1.2	2.5	1997	2001	▲ 1.3	▲ 4
G Project	3	0.56	1.37	1996	2000	▲ 0.81	▲ 4
Average (Variation)	3	(About 122.4%)		(About 3.6 years)		▲ 2.9	▲ 3.6

delayed, claims are often filed between owner and contractors. In certain cases, the claims among contracting parties escalates into severe disputes. For this reason, the analysis of schedule delays in mega projects has received continuous interests from both researchers and practitioners [2], [6], [14], [26], [41], [45].

This paper analyzes delays in the Korea high-speed railway construction project, known as the Korea Train eXpress (KTX) project. The KTX project has a linear property with lots of repetitive works, but it is also extremely complex project with a total length of approximately 412 km. This paper derives lessons learned through the investigation of critical cause of delays in KTX project. The analysis flow is organized by manipulating current analysis methods to be adaptable to the long and linear project based on the conceptual framework tailored for this case study. First, an investigation is performed at the overall project level to find the most delayed sections. Then, a detailed analysis is conducted to investigate the delay causes and their effects. By investigating and comparing critical factors, this research provides recommendations and lessons learned to identify key issues related to project delays for KTX project.

II. THEORETICAL BACKGROUND

A. Systems Approach for Better Project Performance

Systems approach has been applied to better understand various facets of projects. In an effort to investigate and improve project performance, researchers proposed various system approaches [3], [8]–[11], [18], [23], [33], [35]–[39], [42], [43], [45]. Bruelious *et al.* [3] proposed four basic accountability dimensions to be employed in mega project decision making: transparency, performance specification, explicit formulation of regulatory regimes, and the involvement of risk capital. Yeo [45] presented three fresh systems perspectives to achieving innovation and success in infrastructure project: the concepts of large-scale living system, hard systematic thinking, and in-depth preproject planning. Jolivet and Navarre [18] described a new approach to large-scale project management for industry, based on self-organism and meta-rules that allow for greater productivity and a more systematic organizational structure. Shenhar and Dvir [35] and Shenhar [36], [39] have proposed a 2-D typological framework for project classification: four levels of technological uncertainty at project initiation and three levels of system scope, which identifies their position on the hierarchy of systems and subsystems. Furthermore, the same framework has also been found useful in the classification of systems engineering methods [38]. Dvir *et al.* [10] employed a linear discriminant analysis methodology to classify the performance levels of projects. The results suggested that project success factors are not universal for all projects. Different types of projects exhibited different sets of success factors, suggesting the need for a more contingent approach in project management theory and practice. These systematic approaches provide strategic guideline for accomplishing successful project implementation. More recently, project management scholars showed strong research interests in mega projects discussing complexity and challenges of managing large engineering projects, and searching for innovative project management approaches, methods, and frameworks in the Academy of Management Conference [48], [49].

B. Critical Success Factors

The research for critical success factors have been conducted for approximately last two decades, focusing on the project and business level [17], [22], [26], [28], [30]–[33]. Morris and Hough [26] investigated into eight large and complex projects with huge potential economic impact on the society, but were poorly managed, for the purpose of identifying success factors, such as project objectives, technical uncertainty innovation, politics, community involvement, schedule duration urgency, financial contract legal problems, and implementation problems. Pinto and Slevin [30], [32] identified critical success factors generalizable to a wide variety of project type and organization, such as project mission, top management support, project schedule/plan, client consultation, personnel, technical tasks, client acceptance, monitoring and feedback, communication, troubleshooting. Pinto and Covin [31], through a study of 159 research and development projects, developed a project implementation model that focused on certain organizational rules, executive procedures, and environmental conditions.

Lyer and Jha [22] elicited seven critical factors affecting schedule performance from Indian construction projects, such as commitment of the project participants, owner's competence, conflict among project participants, coordination among project participants, project manager's ignorance and lack of knowledge, hostile socioeconomic environment, and indecisiveness of project participants. Poli and Shenhar [33] proposed six keys to project success as the element of project strategy: objective, product definition, competitive advantage/value, business perspective, project definition, and strategic focus. Cerreño *et al.* [7] also discovered five success factors for high-speed rail projects in the USA through a broad literature reviews and three specific case studies: strong leadership by the federal government, accurate cost-benefit analysis, institutionalized support, investment for advanced technologies and approaches, and developing appreciable ridership.

C. Project Performance Evaluation

Significant efforts have been made to evaluate the project performance in mega projects.

Flyvbjerg *et al.* [13], [15] analyzed the cost overrun problems in transportation infrastructure projects multilaterally, based on 258 rail, bridge, tunnel, and road projects with an average worth of approximately US$ 350 million. They also presented empirical evidences that allows for valid economic risk assessment and management of urban rail projects [16]. Frimpong and Oluwoye [17] examined and evaluated the relative importance of the main factors that caused time and cost overruns in groundwater construction projects in Ghana. Merrow *et al.* [47] quantitatively analyzed time and cost overrun problems by examining 52 capital projects ranging in cost from $500 million to over $10 billion (in 1984, constant). They found that the average cost overrun was 88%, and the average schedule delay was 17% measured from the detailed design to the completion of construction.

Previous research on time delays can be categorized into three types: 1) those that evaluate the relative importance of significant factors causing delays in projects [1], [5], [6], [11], [12], [25], [28]; 2) those that measure the delay impact utilizing computerized CPM (critical path method) analysis based on a genuine schedule [2], [4], [23]; and 3) those that compute activity delays and assess their contribution to project delays [19], [40], [41]. Many researchers have investigated and evaluated the significant factors causing delays in mega projects. For example, Chan and Kumaraswamy [5], [6] presented the results of a survey to determine the relative importance of significant factors causing delays of 83 projects in Hong Kong. Five major causes of delays are found to be quite similar to those of Korea mega projects: poor site management and supervision, unforeseen ground conditions, slow decision making of project participants, client-initiated change orders, and necessary variances of work. In investigating the available delay analysis methods, Bubshait and Cunningham [4] presented guidelines for three types of delay analysis such as as-planned method, as-built method, and time impact analysis. They employed these three methods to measure delay impact on genuine construction schedules utilizing computerized CPM analyses. Shi *et al.* [40] also developed a method for computing activity delays and assessing their contribution to project delay. The method consists of a set of equations that can be easily coded into a computer program that allows quick access to project delay information as opposed to the CPM-based tools.

III. Conceptual Framework for KTX Case Analysis

The case study aims to identify key determinants for future mega projects through delay analysis of KTX project with "zoom-in" approach. Zoom-in approach involves focusing on a critical segment or a subproject rather than reviewing the entire project. This approach is useful when discovering specific and critical issues that have large impact toward project goals and objectives by analyzing a small segment or subproject. Based on the previous studies [26], [30]–[33], [35]–[39] for project management success factors, the authors developed a conceptual framework for this case study. Particularly, this study adopts the project success factors of Morris and Hough, and Pinto and Slevin as the basis to analyze case study [26], [30], [32]. These success factors relate to the significant managerial components such as cost and time. This study analyzes causes of delay in KTX project and presents key determinants for mitigating future mega projects' delays.

Prior to conducting an in-depth case analysis on the causes of delay, interviews with five key project managers were conducted, who actively managed the KTX project, to identify any potential issues from this project. The authors carried out the interview process as facilitators in a way to enhance the understanding of the topic of interest. The interviews discovered major problems related to the main causes of delay. The most critical problems raised were frequent design change, deferred land acquisition, lack of technical capability, environmental concerns and public resistance, delayed permits, lack of an overall project control system, and political reasons surrounding this boiling project. Other critical problems include miscommunication within participants, financial problems, conflicts within joint venture, and owner-provided supplies. The analyses of critical problems provide guidelines on finding major causes of project delay and enable in-depth project performance evaluation at the project level. By identifying and analyzing critical problems, this research provides recommendations and lessons learned, applicable to other mega projects that could have major project delays and cost overruns.

The interviewees also indicated that each project segment had unique problems, and chain reactions often occurred where critical delay leads to compounded delay in other sections. Through interviews and extensive literature reviews, probable causes were drawn that were relevant to the delays of the KTX project. All these judgment-based factors were thoroughly investigated

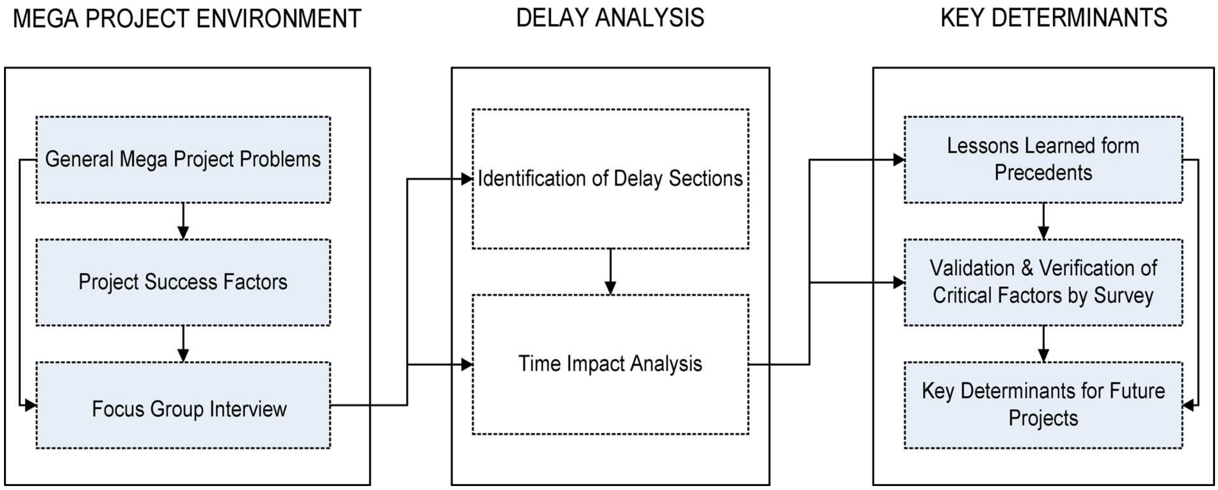

Fig. 1. Conceptual framework for KTX case analysis.

and verified further through the delay analysis method to confirm the views of project participants.

Following the interviews, this study used the "zoom-in" approach as the schedule delay analysis for eliciting key determinants of the mega project. The zoom-in approach consists of two steps. First, various S-curves are compared to find any critical section that impacted the opening date of the total route. Then, the procedural analyses quantify the causes and effects of delays on these critical sections in great detail. Because this paper analyzes the causes of delays in the KTX project after its completion, there is a well-verified as-built schedule. Accordingly, the method is primarily based on the as-built method and time impact analysis that are designed to analyze delay factors and to estimate the impact of delays primarily based on the actual project schedule performance [4]. Through the analyses, we also discern who is responsible for the causes of delay and identify the key work elements of each section, such as specially designed bridges or tunnels that critically influenced the project duration. At last, analysis results are reevaluated and compared through a survey with industry experts.

The scope of this case study particularly focuses on the railway roadbed construction, because the roadbed construction is the most critically delayed work package, compared to others including track-laying, electric work, railroad signal work, and communication facility work. Fig. 1 illustrates the conceptual research framework that identifies a three-stage approach, mega project environment, delay analysis, and key determinants.

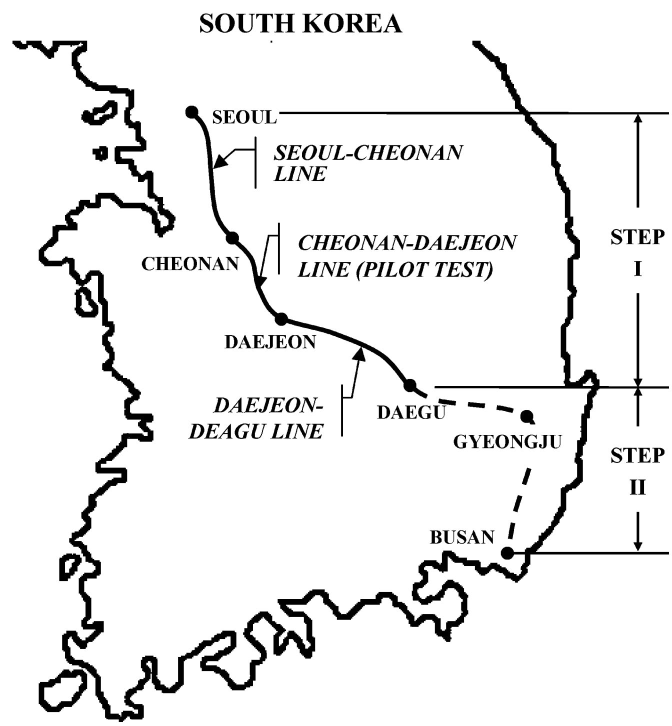

Fig. 2. Route of Korea high-speed railway.

IV. Overview of the KTX Project

The KTX project was planned in 1992 as a national blueprint to revolutionize the Korea's logistics system and to help raise its competitiveness with advanced train-manufacturing technology. The initial plan was set up to build the railway system from Seoul to Busan within seven years. This project was delivered in the form of a traditional design-bid-build and was cofinanced by both the government (Ministry of Construction and Transportation) and operator (Korea Railway Network Agency).

Similar to other mega projects in Korea, the KTX project faced obstacles that have resulted in cost overrun and time delays. The budget ballooned from \$5.8 to \$18.4 billion, and the estimated duration of construction extended from 7 to 12.5 years, which has led to severe burdens on the general public [25]. Due to the huge increases in cost and time, the government changed its initial plan to a stepwise construction. As the first step, a partial route of the KTX was completed and opened from Seoul to Daegu in 2004 (see Fig. 2). The second phase, from Daegu to Busan, is now under construction and will be opened by 2010 (the dotted line in Fig. 2).

KTX project has several unique characteristics with regards to managing project. First, the entire project includes 11 141

TABLE II
CHARACTERISTICS OF THE THREE SEGMENTS

Segments	Seoul - Cheonan	Cheonan - Daejeon (Pilot project)	Daejeon - Daegu
Starting date	1994.12	1992.06	1996.01
Neighboring area	Urban	Rural	Rural
Site acquisition at starting date	Not initiated	Partially completed	Completed
Special purpose law	Partially applied	Partially applied	Fully applied
Delays	Significant	Moderate	Slight

different activities, which signifies the mega scale of the project. Examples of crucial work packages include railway roadbed construction, track-laying, station building construction, storehouse construction, electric work, railroad signal work, and communication facility construction. The railway roadbed construction deserves to get more attentions than other work packages because it is composed of long railway tunnels (39% of total railways), special types of bridges (34%), and other earthworks (27%), which are inherently exposed to many external risk factors for potential delays. Other work packages such as track-laying, electric work that have systematic and repetitive procedures simply follow the roadbed work with less external risks.

Second, the high-speed railroad requires higher quality and safety standards that are fundamentally different from the traditional railways to ensure the safe and sound operations of the high-speed trains. The average train speed of 300 km/h necessitates the use of special designs and construction methods for high-strength structures that can handle high dynamic loadings. The strict guidelines for high-quality structures are applied to the entire route of the high-speed railway.

Third, in addition to the technical difficulties, the railway consisted of 26 different linear sections. If any part of the railway line is defected, the KTX trains cannot operate properly. This also implies that the total route cannot be operated for the general public if the construction of any small part of the railway line is delayed because the train cannot run through the service line from origin to destination.

Fourth, the railway route between Seoul and Daegu is broken down into three segments that have fundamentally different characteristics. The term "segment" is used to refer to the concept that is larger than "section," i.e., a segment comprises five to nine sections. Table II explains the characteristics of the three segments in terms of construction start date, neighboring area, site acquisition status in the beginning of construction, application of special-purpose law, and the level of time delays. The neighboring area characteristics focus on whether the area is urban or rural, and the application of special-purpose law indicates when the special law was applied to lessen the burdens of approvals and permits for the efficient execution of the KTX project. The Cheonan–Daejeon segment, the pilot project for carriage operations, started first, followed by the Seoul–Cheonan segment and then the Daejeon–Daegu segment. The Seoul–Cheonan segment was also located in a relatively more urban area than the others, which made it exceptionally difficult to acquire the construction site in advance. As shown in Table II, the difficulty in acquiring lands caused the Seoul–Cheonan segment experienced the most significant delays, whereas the Cheonan–Daejeon segment and the Daejeon–Daegu segment experienced moderate and slight delays, respectively. This paper focuses on investigating the first phase of the KTX line with the three completed segments (the Seoul–Daegu line).

V. INVESTIGATION OF DELAY CAUSES

A. *Identification of Critical Sections*

The prior interviews discovered the primary problems and potential factors related to the main causes of delay. Based on face-to-face interviews, in-depth delay analysis follows to further identify the critical events or activities that caused the significant delays. It is, however, difficult to analyze the whole KTX project on activity level because the project encompasses a large number of complicated activities. KTX project consisted of three segments with 26 bid sections. The 26 sections were characterized by different site conditions and contractual bid structures, each of which has different reasons for the time delays. As previously noted in the interviews, all of the delays do not necessarily affect the final completion date. Delays that influence the final due date can occur only in a specific part. In this sense, the approach of scheduling with an S-curve makes it worthwhile to identify the critical sections of the railway route. For an ideal situation, earned value management system (EVMS) can be effectively used for delay analysis, rather than the actual cost-based S-curve method. However, EVMS had not yet been implemented in the KTX project and the earned value data were not obtained. Therefore, the study used the applicable actual cost-based S-curve analysis. The overall progress can be seen at a glance with the progress curve of each section as shown in Fig. 3. Through the S-curve comparisons of the 26 sections corresponding to the Seoul–Daegu line, the most delayed areas were found to be sections "2-1 (15.5 km)," "5-1 (9.4 km)," and "8-2 (16.9 km)" (code numbers of each section).

These three sections involved most of the critical delay factors that influenced the final opening date, whereas other sections were completed ahead of the due date. Most of the delays in the first phase of the KTX project—around 4.5 years out of 5.5 years total delay—occurred in these three sections. Particularly, four years are extended only from the most critical section, "2-1" in the Seoul–Cheonan segment. Even worse, it shows that approximately 2.5 years were already lost before the cumulative progress rate reached 20%. Through a time-series analysis at the macrolevel reflecting chronological causes of delay, it was found that the most influential reasons for delay in this section were mainly attributed to the deferred land acquisition, a lack of owner's ability and strategies in planning a complex project, frequent changes of routes triggered by poor underground investigation, and severely lagged permits or approvals in the early stages of construction. For example, the construction was

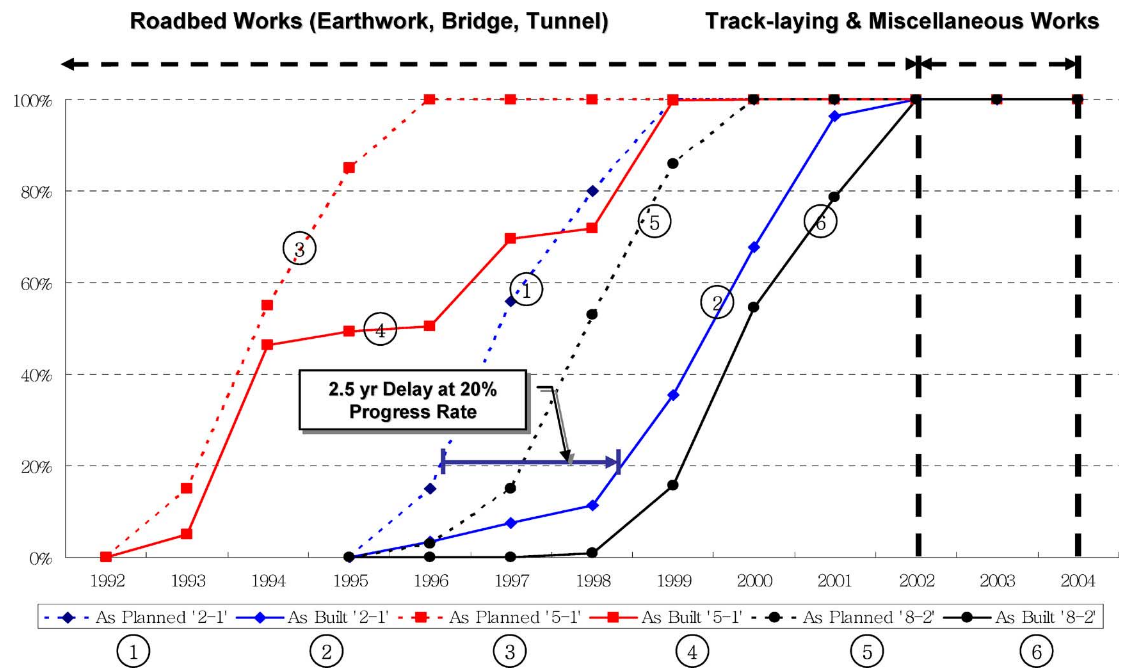

Fig. 3. S-curve comparisons on critically delayed sections.

suspended temporarily for about two years from 1996 to 1997 because an abandoned mine near the railway tunnel was discovered, which resulted in the change of the railway route and its redesign of a line accordingly. This route change, along with other delay causes such as deferred land acquisition incurred by design modifications, unforeseen physical obstacles forced the KTX project to experience the ripple effect with huge delays of four years from just one part of the 26 sections. In summary, "2-1" section in the Seoul–Cheonan segment that had the longest delay among the three segments already showed great delay from the initiation phase and it successively resulted in the delay of completion date of "5-1" section and subsequently two years delay of the construction starting date of "8-2" section. This first analysis identified the most delayed sections and traced delay factors at a glance. Based on these results, procedural analysis follows to provide the details of delays, focusing specifically on the critical sections.

B. Impact Analysis Through Comparing Planned and Built Schedules

As a means for time control and actual project execution, the owner of KTX project used the CPM method, by implementing the popular project scheduling software—Primavera Project Planner. As previously mentioned, the KTX project consisted of 11 141 activities. First, we compared the as-planned and as-built schedules for finding critically delayed activities, focusing on aforementioned three sections: "2-1," "5-1," and "8-2". The details of this process consist of the identification of delayed activities, the estimation of delayed days, and the identification of delay causes. As shown in Fig. 3, section "2-1" is the most delayed among the three critical sections. In comparison to its original due date (1563 days), the total actual duration jumped to 3014 days, which implies a total delay of 1451 days (around four years). Based on this activity-level comparison, we performed an impact analysis of how much delays these critical activities induced to the successive activities in the next section.

Section 2-1 consists of 16 major activities including "BANWOL Bridge" and "PALGOK Bridge." The predecessor of these activities was "site acquisition" and the delay of "site acquisition" affected the starting date of other bridges and tunnels construction, which led to the delay of track-laying construction. The delay of "site acquisition" was caused by strong resistance of public residents who were concerned about receiving proper compensation from high real estate value and potential ecological/environmental impact because most construction sites were located in high-density metropolitan areas. The planned critical path was "land acquisition" → "BANWOL Bridge" → "PALGOK Bridge"; however, the actual completed schedule showed that the completion date of most of the major activities were very close to the critical path due to the significant effect of delays in the planned critical path that pushed the completion date of other successive activities. In different case of typical highway construction, a delay in one section will not affect other activities or overall schedules because many sections can be divided individually and constructed simultaneously. However, in the KTX project, the delay of critical path affected the starting date of other activities that had large total float because of High-speed Railway's unique rail welding system of having no expansion joint. This unique welding method makes it impossible to construct different sections of railway concurrently and connecting them by using expansion joints because it requires all previous activities along the line to be thoroughly completed before starting the track-laying activity.

Using the as-built method, this study further identified the causes of the delayed activities on the critical path. The

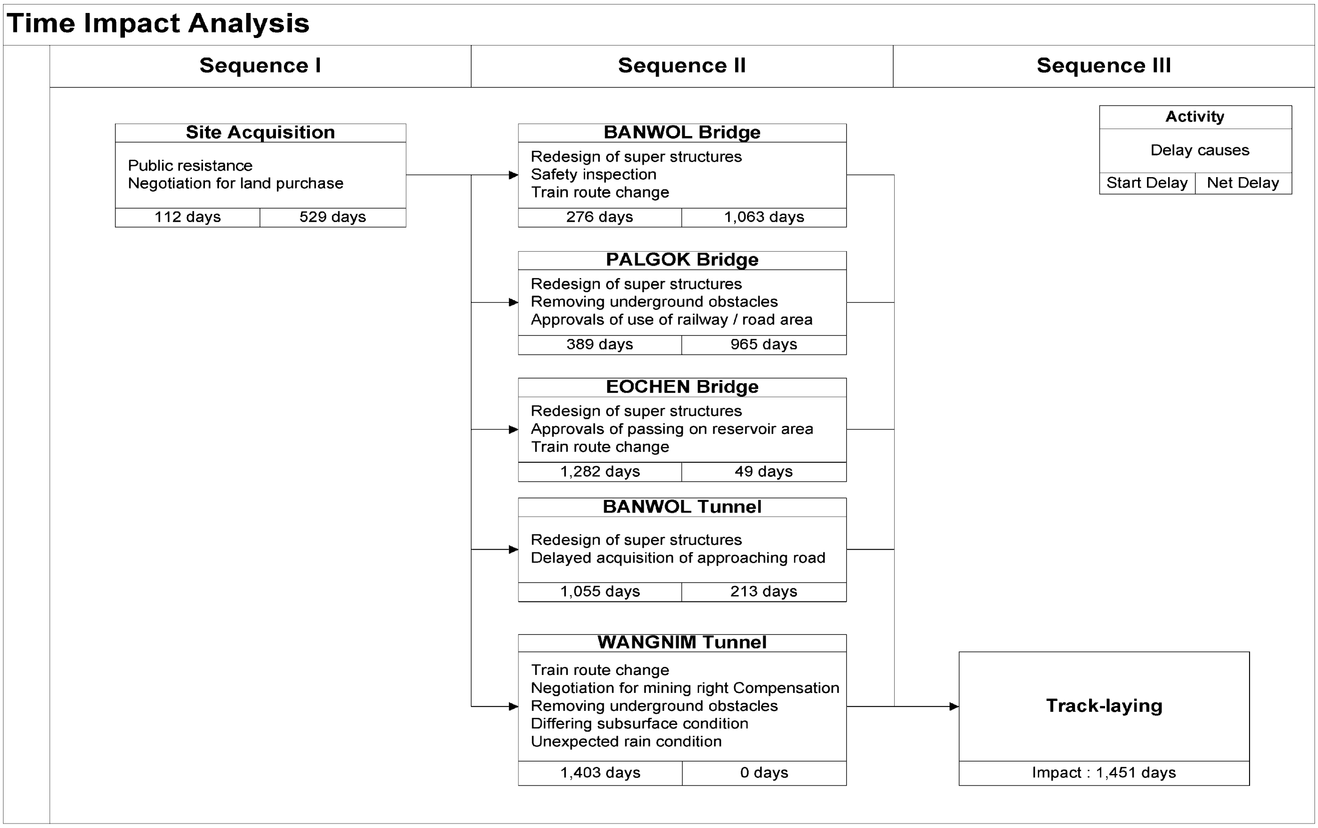

Fig. 4. Time impact analysis in section “2-1.”

estimation of delay impact can use three different types of delay concepts: start-delay, net-delay, and total-impact [4]. The start-delay means the lag between a planned start day and an actual start day. The net-delay is calculated by subtracting the free-float amount from an activity delay in the construction progress phase. Finally, the total-impact is estimated by adding a start-delay and a net-delay together. In brief, the calculation processes consist of following steps.

1) Find the critical path in the section to analyze delay impacts.
2) Calculate the early start, early finish, and duration of activities along the critical path from both the “as-planned” and “as-built” schedules.
3) Estimate the start-delays and net-delays by comparing the “as-planned” with “as-built” critical path.
4) Calculate the total-impact by adding the start-delay and net-delay together.

Section “2-1” has six delayed activities on the critical path. Fig. 4 shows the start-delay and net-delay of each activity that were estimated. The analysis of the delayed activities indicates that most of the delays occurred in the form of start-delays during the initial stage because “site acquisition” was notably deferred. It is interesting to note that the major delay of “site acquisition” was followed by a chain of delays, propagating the start-delays toward the succeeding activities (see Fig. 4). As stated, section “2-1” was located in urban area, which made it exceptionally difficult to acquire the construction site. Moreover, this section was more triggered by political reasons such as requirements of changing or adding stations nearer to their towns by local governments, excessive and strong pressure to route changes so as to bypass or underpass their downtown areas, or other legal reasons that deferred the steady pace of site acquisition. It implies that the initial delay was rather caused by political or legal reasons than those by technical or managerial ones.

As for the other critical activities displayed in Fig. 4, technical reasons such as unforeseen physical obstacles, water mains, gas pipes, telecommunication cables, and electrical power transmission towers also caused the project activities to suffer from net-delays. Extremely, the discovery of an abandoned mine prompted the stoppage of construction, which led to the route change and successive change order process. This was due to the poor site investigation of the underground conditions during the design phase. Propagating to the successive activities, it caused a ripple effect generating the delays in other predefined or new activities, such as design modification, additional site acquisition, and further earthworks because, due to the safety reason, the original tunnel line surrounding the abandoned mine was inevitably changed to the alternative embankment route instead of the unsafe tunnel line.

Another critical reason for delay can be classified by structural characteristics, which is related to the technical uncertainty innovation factor suggested by Morris and Hough [26]. The high-speed train runs at a speed of 300 km/h. Therefore, there are various complicated and dynamic phenomena such as the fatigue failure from high-frequency vibration, instability

TABLE III
COMPARISON OF THE THREE CRITICAL SECTIONS

	"2-1" (Seoul – Cheonan)	"5-1" (Cheonan – Daejeon)	"8-2" (Daejeon – Daegu)
Total Delays	1,451 days	986 days	195 days
Type of Delays	Start-delay: 112 days Net-delay: 1339 days	Start-delay: 641 days Net-delay: 345 days	Start-delay: 0 days Net-delay: 195 days
Critical Delay Causes	• Route change • Deferred site acquisition • Structural design changes • Delayed approval and permits on train route • Underground obstacles (abandoned mine)	• Deferred site acquisition • Structural design changes • Public resistances	• Public resistances • Cultural property unexpectedly excavated

from the resonance of a structure, and the rapid change of pressure in tunnels. An example of the extreme dynamic behavior is the resonance phenomenon that occurs when the natural frequency of vibration is equal to the vibration frequency of the train load. The dynamic behavior of resonance can produce distress in the structures, which can lead to the collapse of the entire bridge. Thus, it is reasonable to note that the structural designs should be followed by the adoption of high-speed train system because the detailed design codes are basically depending on the carriage system. The France Train à Grande Vitesse (TGV) won the international bid to supply the high-speed trains against German InterCity Express (ICE) and Japan's Shikansen. The Korea government, however, could not make the final contract with the TGV system no earlier than August in 1994 by the lengthy evaluation/negotiation processes and other political reasons. Accordingly, after the structural designs were originally produced based on the traditional design codes in 1991, the whole designs had to be reproduced to satisfy the upgraded higher technical standards required for the TGV train system. The public concerns were also triggered by the results of safety and quality inspections performed by the National Agency of Auditing, revealing lots of poor-quality substandard structures.

Similar to section "2-1," section "5-1" experienced a total of 986 days of delay. It was located in a relatively urban area and started first as a pilot line for testing carriage operations. Also, the special law was applied during the construction so that the owner of KTX experienced frequent delays in acquiring permits or approvals from the local governments. In comparison to section "2-1," the start-delay of site acquisition, estimated at around 641 days, was more critical than that of section "2-1" (113 days). This section was started first in 1992, but highly lagged until 1994 because this initial start-delay was primarily due to the incompleteness of detailed design and redesign of routes accordingly. In addition, it took more than two years to earn a 10% of progress rate, which was achieved from 40% to 50% accumulative rate. It is found that this huge retardation in the middle of construction was stemming from the design verification of superstructures against the dynamic behaviors in conjunction with recurrent reworks due to the public concerns as to elevated quality and other repairing works to cure the serious defects developed in the main structures. For example, the KTX owner contracted with a US-based consulting firm—WJE—to investigate main bridges and tunnels to secure the safety and quality issues that were seriously raised by the general public and other third parties. In consequence, it took another year to confirm the key defects indicated by the WJE and restore them to healthy conditions by curing the critical problems.

Unlike sections "2-1" and "5-1," another section ("8-2") located near the rural area was started after implementation of the special purpose law so that it robustly promoted the site acquisition and lessened the burdens in obtaining the laborious permits/approvals. As a result, total delay is estimated at 195 days, indicating no start-delay and relatively slight setback in net-delays. Table III shows the comparison of these three delayed sections on the critical path. This can be explained by the fact that the owner had learned constructive lessons from the previous performance by which he could improve the ability to perform the complex project and accelerate the project progress through the avoidance of start-delay particularly during the initial stage of this section. Moreover, structural designs were fully carried out following the upgrade of design codes and

TABLE IV
DELAY FACTORS GROUPED BY RESPONSIBILITY

Responsibility	Groups of delay factors	Delay factors grouped by responsibilities	2-1	5-1	8-2	Delay types
Owner's responsibility	Design changes	Redesign of super structures	√			Excusable
		Differing subsurface soil condition	√			
		Change of temporary road location	√			
		Redesign of open culverts	√			
		Redesign of bridge piers			√	
		Change of soil load and dump areas		√		
		Change of intersection location			√	
		Change of station location			√	
	Deferred site acquisition	Main construction areas	√	√		
		Supplementary areas	√	√	√	
	Physical obstacles	Underground obstacles	√	√	√	
		Electric poles / Transmission towers		√	√	
		Tomb areas	√	√		
		Discovery of cultural properties		√	√	
	Delayed approvals and permits	Road occupation	√		√	
		River occupation	√		√	
		Existing railway occupation	√	√	√	
		Building of temporary structures	√			
Joint responsibility	Environmental problem and Public resistance	Noise / Vibration / Dust	√	√	√	Excusable non-compensable
		Underground water dissipation	√			
	Miscommunication	Owner-provided supplies			√	
Contractor's responsibility	Financial problem	Bankruptcy of subcontractors	√			Non-excusable
		Conflicts within joint venture	√			
	Technical problems	Reworks based on substandard quality	√	√		
		Safety inspection		√		
		Shortage of skilled labor	√	√		

Note: The checked cell (√) indicates that the delay factor was incurred in the specified section.

the verification of superstructures with sufficient care, which was not possible in the premature cases of the section "2-1" and "5-1."

Plainly stated, the delay of section "8-2" was largely due to technical reasons. This section "8-2" had a peculiar problem of the slope adjustment on the train route. Also, one of the most significant delay factors was the dissipation of underground water in tunnel construction. The seepage of underground water brought about structural instability in the ground because the lowered level of underground water reduced the pore water pressure supporting the underground structure.

Briefly, the section "2-1" being the most influential cause of the project delay, the total delay induced by all three sections were estimated at 1633 days (around four and a half years). The previously mentioned causes were coupled with each other to have their combined impacts on the whole project delay. In summary, the KTX project was delayed by 5.5 years in the first phase. Of those years, four and a half years were caused from these three critical sections out of the total of 26 sections. Notably, four years out of the four and a half years were generated from the most critical section—"2-1."

C. Other Unique Aspects of Delay Causes

As mentioned, this project was delivered in the form of a traditional design-bid-build. Clearly, it was ineffective to verify the quality of design and constructability and to reinforce the collaborative coordination between design and construction. Further, it was not possible to apply the fast-track method to accelerate the schedule in this type of delivery system. In this sense, the owner bears the main responsibility for the critical delays. With respect to the sources of responsibility, Table IV presents the delay factors, portrayed in accordance with the origins of responsibility. It is found that approximately 80% of the delays were excusable. It indicates that the owner's request for design changes and delayed site acquisition provoked a huge delay in the early stages of the project.

The conflicts that occurred between the owner of KTX and the local Korean governments/public agencies were also natural in this case. In Korea, a number of permits or approvals should be acquired including temporary closure of current facilities in use, methods of how to cross existing roads, existing bridges, or rivers, acceptance of environmental impact assessment, and other 20–30 more permits that can trigger the schedule of construction. Usually, the local governments tended to put excessive burdens to change a route that bypass or underpass downtown areas or to add new stations for their backyards before allowing construction permits, which often led to cost increases and time delays. As the result of the conflict between these parties, the project was delayed over a month only if one permit would be delayed intentionally. The delays due to these conflicts were very critical to the sections of "2-1" and "5-1" because the special purpose law that enacted to promote the permits and simplify the complex and long-lasting approvals issued by local governments was not effective until 1995. It can be explained by the fact that section "8-2" that started after the implementation of the same law experience slight delays while "2-1" and "5-1" sections experienced significant delays. The case illustrates that a badly managed conflict between central and local government delivers undesirable impacts that create both start and net-delays from frequent stoppages while redesigning the routes horizontally or vertically to address the local interests. This cause is very analogous to the previous research, such as "transparency or explicit formulation of regulatory regimes" for the success of a project suggested by Bruelious *et al.* [3] and "social consensus or community involvement" as one of critical success factors proposed by Morris and Hough [26].

Lastly, the owner used CPM for actual project control. It is one of the most significant deficiencies in that the owner could not recognize the critical sections or parts in a timely manner that possibly influenced the opening deadline. For this large and linear project, CPM has limitations, particularly viewing productivity of individual activities as their progress and forecasting delays in their early stage. Project managers should consider an alternative versatile tool such as linear scheduling method (LSM), which is effective in planning linear and continuous projects [44].

VI. Comparisons and Lessons Learned

Through a series of delay analysis, this paper presents the delay factors in the critically delayed sections. The most common delay factors found in the critical sections primarily involve deferred site acquisition, frequent design changes due to the improving quality standard, delayed approvals and permits, public resistance and appeals, and the owner's inexperience in managing mega project. The start-delays occurred mainly in the early stages of the project largely due to insufficient site acquisition and delayed approvals and permits. In the construction stage, various public concerns sometimes resulted in stoppages of the construction works and successively caused time and cost overruns. These results reflect a poor performance, which is quite relevant to the political, legal, technical, and managerial reasons that commonly arise from failed mega projects.

There were precedents of other high-speed railway construction projects such as ICE in Germany, TGV in France, and Shinkansen in Japan. These projects were also delayed in the construction phase and there were many controversies involved in executing the projects. In the case of Europe, the significant causes of delay were highly related to environmental problems. For example, the ICE project was originally designed to pass through a bird protection area. However, concern over the environmental problems spawned very crucial issues, forcing the German government to set up the plan to minimize the impacts from these disturbances. Despite such efforts, public resistance to new lines as well as old lines upgraded was so rigorous that it resulted in huge delays and overruns [34]. Ultimately, due to the increasing needs for environmental protection, the owner/operator inevitably decided to revise the initial design by installing a protection wall along the railway route, 6 m high and 6 km long. Accordingly, the project duration was extended by about one year mainly due to this change. In the case of TGV, the planning for Méditerranée line began in 1989, but there were many monuments and archaeological sites on this line. In addition, environmental protests were also serious in France case. The first environmental protests against a high-speed line occurred in 1990 during the planning phases of the TGV, Méditerranée line. On account of these protests, the French minister of transport had to delay the public announcement of the final route [27]. Project directors were especially worried about environmental damage to the Luberon National Park. For these reasons, it took 30 months to decide the location of the main line through more than 2000 meetings. Although the plan of the TGV was publicly announced in October 1992, actual construction could start no earlier than September 1995 due to this adjustment. This shows that the significant delays in Europe cases were largely related to environmental problems.

On the other hand, in the case of Japan, the main delays were generated from slow site acquisition in metropolitan areas and other technical problems such as defects in the bridge design, and noise and vibration issues in downtown areas [46]. Delay causes of the KTX were similar to those of Japan, but the KTX is more mixed with other various causes and effects. Table V shows the summary of delay causes of precedent cases.

As noted, the KTX project is a representative case from which an owner or operator should realize the importance of project management in the early stage of a project. Based on the case analysis, along with the aforementioned conceptual framework, the authors have added a survey with industry experts to derive valuable lessons as well as to identify their perceptions to actual situations of the delays. We mailed the survey questionnaire to 100 experts who were involved in the KTX project for a number of years and 60 of them participated in the survey. First, the authors solicited them to rank each cause of delays that were drawn from an in-depth analysis. The questionnaire

TABLE V
DELAY CAUSES OF HIGH-SPEED RAILWAY PROJECTS IN DIFFERENT COUNTRIES

	Delay Causes of High Speed Railway Projects
Shinkansen (JAPAN)	• Insufficient site acquisition • Defects in bridge design • Noise and vibration in downtown
ICE (GERMANY)	• Change order for a bird protection area
TGV (FRANCE)	• Change order for monuments and remains area • Negotiation for protection of a national park
KTX (KOREA)	• Insufficient site acquisition • Change order due to improved technical standards • Insufficient geological survey • Noisy and vibration in downtown • Public Resistance for environmental protection

TABLE VI
MAJOR DELAY FACTORS IN EACH SECTION (TOP 5)

	Critically delayed sections		
Ranks	"2-1" (Seoul – Cheonan)	"5-1" (Cheonan – Daejeon)	"8-2" (Daejeon – Daegu)
1	Route change due to abandoned mine (Significance = 4.67)	Design verifications and reworks due to defective quality (4.22)	Changes of pier locations due to seepage of underground water (3.41)
2	Redesign of superstructures due to dynamic behavior (3.71)	Redesign of superstructures due to dynamic behavior (3.83)	Superstructures changes at cross sections over the existing roads (3.36)
3	Owner's inability and inexperience (3.67)	Owner's inability and inexperience (3.22)	Discovery of historical relics and cultural properties (3.18)
4	Other vertical line changes due to conflicts between public agencies (3.57)	Additional Design of Stations required by local governments (3.18)	Public resistances on noises and vibrations (3.14)
5	Delayed site acquisition (3.48)	Public resistances on noises and vibrations (3.11)	Requirement of additional soil pits and soil dumping areas (3.05)

Note: The values in parentheses denote the average significances, measured by Likert scale (1 – 5).

consists of two main parts: 1) personal perception on the relative significance of each cause of delays and 2) open suggestions for avoiding huge delays in this type of mega projects. The significance of each cause is measured by a five-point Likert scale. If the significant level of one factor is higher than the other, the former is considered more significant. As a result, the effect of the degree of delay factors appeared especially differently in each section (see Table VI). Interestingly, those of practitioners' perceptions on the causes of delay are almost coinciding with factors drawn in the previous analyses. However, they ranked factors relevant to technical reasons more critical than those of political or legal reasons. Perhaps, it can be explained by the fact that they were prone to conceal the underpinning political reasons or to recognize technical factors more tangible. We endeavored to uncover these background causes from open discussions with those experts to take key lessons.

In the second part of a survey, we asked to express their opinions as useful lessons that can be used to handle other delays in similar cases. The following is a summary of the identified lessons.

1) The critical delays in the KTX project occurred in the early stages of the project, so the time and cost aspects of the project were enormously affected. As pointed out by Pinto and Slevin [30], [32], it highlights the importance of the government/owner's role to coordinate the various interests among the government organizations or other participants. The KTX project was influenced by the complexity and ambiguity of the roles and responsibilities between the participants. There was a lack of early project management from the owner's viewpoint, and as a result, proactive problem-solving through the appropriate communication tools was not satisfactory. It was well highlighted by Yeo [45], requiring an "in-depth preproject planning" to achieve the success of infrastructure project. It also points out the need for social consensus to avoid potential conflicts and disruptions triggered by inadequate planning and hasty implementation of huge-scale projects when a large number of organizations and bureaucratic procedures are involved. As result, this project was considered similar to the representing case of "a lack of realism" and "the overoptimism" that were critically addressed by Flyvbjerg *et al.* [14], and Lovallo and Kahneman [24].
2) Another important factor is mainly attributed to the exacting technological requirements for satisfying the higher quality standards of the high-speed railways. Morris and Hough, and Pinto and Slevin pointed out this factor as "technical uncertainty innovation" and "technical tasks" [26], [30], [32]. The unverified design required frequent change orders and reworks, which subsequently caused continuous delays to the successive progresses. To overcome this inherent problem, it is recommended to apply the proper delivery systems such as design-build or another innovative/alternative bidding process so that a chain effect due to redesigns can be minimized and a fast-track system also can be implemented. It can be explained by the useful discussion of Jolivet and Navarre [18], suggesting that large-scale project management requires a new approach based on "self-organism and meta-rules," which allow for fast and systematic production structure by integrating design and construction phase.
3) One of the critical factors in the case of KTX is the improper and tardy acquisition of work sites (right of way), particularly where cultural properties or historical relics are buried. As the work site was not secured, the start-delay increased continuously in the early stage of the project. Accordingly, it was essential to investigate work fields

and negotiate with landowners to acquire sites as early as possible in the preconstruction phase. In particular, it was difficult to expropriate the sites in the metropolitan areas. Since the land expropriation of the main line was postponed, it affected the total delay of the project in various ways. For this reason, it is necessary to establish an effective land acquisition plan during the design phase by expediting the design works, particularly prioritizing the specific sections passing through urban areas or other historical regions to advance the land acquisition process.

4) This case also shows the importance of risk management and a monitoring system in overall project management, as stated by Flyvbjerg *et al.* [14]. The respondents well recognized that the scheduling method was limited and inappropriate for this project. The mega projects have multiple delay factors, and therefore, the most important role of the project mangers is managing risks before delays and coping effectively with crises after delays. Most delay factors are controllable risks. However, when one of them occurs, the impact of delay will be great. Therefore, it is important to manage a delay crisis, especially focusing on the significant parts or sections to secure the due opening day. Accordingly, it is necessary to construct a totally integrated monitoring system, aiming at controlling delays from the viewpoints of both the macroscopic and microscopic levels. This tool provides an overall picture for the whole project, and also for the specific delayed parts of each section that need support from the project participants to avoid irrecoverable delays to the opening date.

Consequently, the derived critical factors for poor performance of the KTX project came from the linear and complex nature of large-scale construction projects. In general, the linearity is shown in network-type construction projects such as highway, railway, oil pipeline construction, etc. These construction projects have repetitive multisections that can be built concurrently. Each section is viewed as relatively independent of other sections for design and construction. However, this does not mean that the project is simple to manage because there are few sections that are unique and different from other sections. In fact, the whole project should be coordinated with extra caution to manage and control the interrelated schedules effectively. Apparently, planning complicated and interrelated concurrent processes of subprojects in KTX project, and managing and allocating large number of human resources resulted in delay of a project. This result was also well addressed by the useful discussion of Clegg and Pitsis [49].

VII. Conclusion

This study focused on the causes and impacts of project delay in the KTX project. The KTX project had major schedule delays and cost overruns. This paper particularly analyzed the delays of this mega project. In particular, the most critical section "2-1" was attributed to a four-year delay out of the total of five years that resulted from deferred site acquisition and redesigns of structures to meet the upgraded design codes. During project initiation, the lack of advanced technological knowledge and owner's experiences contributed to delays in project. In addition, inaccurate geological surveys produced significant reworks, and unexpectedly, underground obstacles caused frequent changes of railway routes, which propelled successive delays toward the downstream activities.

In-depth discussions from the experts involved in the KTX project derived valuable lessons learned. In this process, most interviewees were project managers for owners; therefore, interviews could have been biased to favor the owners. To collect unbiased information, the authors asked the interviewees to provide additional information related to issues and problems of the KTX project to validate their responses and minimize the favoritism. Tardy acquisition of work sites, frequent changes of construction specifications and lack of owner's project management skills were all identified as significant reasons for the project delay and cost overrun. The subtle and obvious disharmony between central government and local governments also affected numerous changes in plan and schedule. All these factors had direct impact toward project delay.

This study has significant implications for project managers despite the limitations and challenges. This paper identifies and analyzes the causes and impacts of delay on mega project, which is linear and complicated like the KTX project. The study indicates that project managers should consider various social and political factors in addition to time, cost, and quality, to manage a project successfully. When potential delay causes are identified early, the delayed activities can become a part of the as-built critical path. Often, more serious delay factors tend to be found on the updated critical path of the critical sections. Project managers should find proper measures to address delays and conduct proactive actions by utilizing the multilateral approach suggested in this study. Identifying delay factors in the critical sections, both in macro- and microlevels, could lead to successful project management of mega-scale projects.

Future research will focus on developing a time–cost analysis framework by analyzing the causes, concurrent impacts of time and cost overrun, and financial impacts toward project delay. Identifying and mitigating project risks and quantifying the impact of social and political risks for mega project is also a subject of future study. By adopting a guideline and lessons learned from KTX project, one can better identify critical causes of schedule delays and cost overruns for evaluating mega-project performance.

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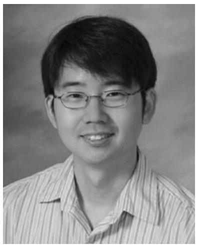
Seung Heon Han received the M.S. degree from Seoul National University, Seoul,Korea, and the Ph.D. degree in construction engineering and management from the University of Colorado at Boulder, Boulder.

He was the Director of the Ministry of Construction and Management, Korea. He was also in charge of planning, financing, and managing mega construction projects. He is currently an Associate Professor of the School of Civil and Environmental Engineering, Yonsei University, Seoul. He has authored or coauthored more than 40 scholarly publications in the area of international project risk management, productivity and production improvement, and cash flow forecasting. His current research interests include systematic and integrated project management principles and toolkits including emerging technologies, decision support tools, and operations/processes simulations.

Dr. Han is a member of the American Society of Civil Engineers.

Sungmin Yun received the M.S. degree in construction management and information from Yonsei University, Seoul, Korea. He is currently working toward the Ph.D. degree in construction engineering and project management at the University of Texas at Austin, Austin.

He was an Assistant Research Fellow for Korea Research Institute for Human Settlements, Korea. His current research interests include project management, risk management, financial management, information technology, and engineering and construction management.



Hyoungkwan Kim received the M.S. degree in applied mechanics from Yonsei University, Seoul, Korea, and the Ph.D. degree in construction engineering and project management from the University of Texas at Austin, Austin.

He was an Assistant Professor at the University of Alberta, Canada. He is currently an Assistant Professor of the School of Civil and Environmental Engineering, Yonsei University. He has significant research, education, and industry experiences, in the area of construction project management. He has numerous publications in both academic and trade journals, including *Journal of Construction Engineering and Management*, *Journal of Computing in Civil Engineering*, *Transportation Research Record*, *Computer-Aided Civil and Infrastructure Engineering*, *Automation in Construction*, and *Canadian Journal of Civil Engineering*. He is currently an Associate Editor for *Journal of Computing in Civil Engineering*.

Dr. Kim is a Registered Professional Engineer (P.Eng.) of the Association of Professional Engineers, Geologists, and Geophysicists of Alberta (APEGGA), Canada.

Young Hoon Kwak received the B.S. degree from Yonsei University, Seoul, Korea, and the M.S. and the Ph.D. degrees in engineering and project management, respectively, from the University of California, Berkeley.

He is a Faculty Member of the Project Management Program at The George Washington University's School of Business (GWSB), Washington, DC. He was a Visiting Engineer at the Massachusetts Institute of Technology, Cambridge, and taught at the Florida International University, Miami, FL, before joining GWSB. He is the author or coauthor of more than 70 scholarly publications in the area of strategic issues in project management, project risk management, project control, performance improvement, and engineering, construction, and infrastructure management. His publications appear in *California Management Review*, the IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT, *Technovation: The International Journal of Technological Innovation, Entrepreneurship and Technology Management, the International Journal of Project Management, Project Management Journal, the International Journal of Managing Projects in Business, Risk Management: An International Journal, the Journal of Construction Engineering and Management, the Journal of Management in Engineering, the Journal of Computing in Civil Engineering, Korean Management Review, ICAFAI Journal of Operations Management, Projects and Profits, PM Network*, and others. Currently, he is a specialty editor (associate editor) for case studies section of the *Journal of Construction Engineering and Management* (ASCE) and serves on the editorial board for *International Journal of Project Management* (Elsevier), *Project Management Journal* (Wiley), and *Journal of Management in Engineering* (ASCE).

Dr. Kwak is an elected member of the Construction Research Council of American Society of Civil Engineers and a three-time recipient of the Project Management Institute's research grant.

Hyung Keun Park received the M.S. and Ph.D. degrees from the University of Wisconsin-Madison, Madison.

For more than 20 years, he was with Daewoo Engineering and Construction Company, Korea, and has been the General Manager. He is currently a Professor in the Department of Civil Engineering, Chungbuk National University, Chungbuk, Korea. His current research interests include information technology of construction job site and construction business.

Prof. Park is a member of the Korean Society of Civil Engineers.

Sang Hyun Lee received the M.S. degree from Yonsei University, Seoul, Korea.

For more than 13 years, he was with Korea High Speed Rail Construction Company, Korea, where he was engaged in railway construction project planning and controlling. He is currently the Manager of the Department of Honam High Speed Rail Design, Korea Rail Network Authority, Seoul, Korea. His current research interests include application of information technology for the efficient management of mega high-speed railway projects and implementation of risk management system for this type of projects and other construction business.