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The Relation between Lean Construction and Performance in the Korean Construction Industry

by

Seong Kyun Cho

A dissertation submitted in partial satisfaction of the

Requirements for the degree of

Doctor of Philosophy

in

Engineering-Civil and Environmental Engineering

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Herman Glenn Ballard, Co chair
Professor Iris D. Tommelein, Co Chair
Professor Laura Stoker
Professor William Ibbs

Spring 2011
The Relation between Lean Construction and Performance in the Korean Construction Industry

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by

Seong Kyun Cho
Abstract

The Relation between Lean Construction and Performance in the Korean Construction Industry

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Seong Kyun Cho

Doctor of Philosophy in Engineering – Civil and Environmental Engineering

University of California, Berkeley

Professor Herman Glenn Ballard, Co-Chair

Professor Iris D. Tommelein, Co-Chair

The construction industry of South Korea takes a relatively big portion of the nation’s economy. A common sense is that, if there are systematic problems hindering project performance in the industry, the overall economy of the nation might be harmed to a high degree. This concern has already been raised by some industrial researchers’ and in some public sectors research projects. If we can diagnose the industry in terms of the appropriate causal factors improving performance, we can make recommendations to improve the industry. That presumption is the motive of this research.

Lean Construction has developed many components such as ‘Incentive based on integration,’ ‘Set Based Design (SBD),’ ‘Process Improvement based on Value Stream Analysis (VSA)’ and ‘Production control based on plan reliability, Last Planner™ (LP)’ in order to bring value that the owner exactly wants instantly without waste. Many research projects and relevant national innovative movements in the USA, Hong Kong, the UK and Singapore support the hypothesis that Lean Construction improves project performance.

The research hypothesis that Lean Construction improves project performance was confirmed by the survey on several projects that were believed to have employed Lean Construction to a certain degree, which showed strong correlations between the ‘LP’ and project performance, and between the ‘Incentive based on integrity’ and performance. Considering the ‘LP’ is known as the most popular tool of the Lean Construction, this result is very encouraging and leads to recommending Lean Construction to the Korean industry. In addition, the two effective components, ‘Incentive based on integrity’ and the ‘LP,’ are inter-correlated, which means they are indispensable to each other in order to achieve better performance.
To make effective recommendations, I diagnosed the Korean Construction Industry with a more detailed survey measuring Lean Construction and project performance using a stratified random sample. Only SBD was strongly correlated with project performance but additional interviews and analyses pointed at the reason why the other components of Lean Construction have not been effective in the Korean industry. For example, the LP demanding specialty contractors’ participation is not appropriate because a general contractor in Korea selects his/her specialty contractors after completing most of the schedules so that we cannot expect any specialty contractor to participate in that scheduling effort. Value Engineering has been developed to be just another form of a change order to relieve an owner’s burden of issuing an official change order. In addition, even SBD was proven to be seriously correlated with Point Based Design (PBD) that has been used as the concept opposite to SBD because the relevant regulations force the design processes to be separated contractually, so that most of the survey respondents could not imagine any collaborative design without recalling PBD.

Based on the survey and supplementary case studies, this research produces policy recommendations to the Korean Construction Industry for better market competitiveness. For example, 1) Based on the current state that there has been no criterion evaluating the degree of production control, I recommend that bid evaluation criteria should include measurement of implementation of production control achieved by means such as LP; 2) Based on the current state that the bid evaluation criteria of Design-Bid-Build (DBB) stick to superficial numbers such as financial credibility or proximity of the bid price to a certain level (e.g., 88%) of the estimated price determined by chance, which do not incentivize project performance, I recommend that past project performance as an incentive for better performance should be more dominant than the aforementioned superficial numbers in the bid evaluation criteria; 3) Based on the current state that Design-Build (DB) and Alternate Design Bid (ADB) have produced negative iteration in design and have maintained a bid evaluation system much more favorable to the biggest construction companies, I recommend that a schematic design, the most important bid document in DB and in the modified version of ADB (in this research\(^1\)), should be simplified and customized so that the evaluation becomes more realistic in selecting the bidder; and 4) Based on the current state that many barriers among construction works such as separation of electrical works from a whole project actually, I recommend that the barriers be removed in order to achieve more project integrity.

In conclusion, the Korean Construction Industry has not been familiar with integrated approaches toward project performance and has maintained unclear attitudes toward the market competitiveness so that many Korean Project Delivery Systems have not taken advantage of their merits. This research contributes to knowledge in that it suggests how to renovate the Korean Project Delivery Systems in terms of Lean Construction, the principles to achieve the best performance, and does so with clear academic support.

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\(^1\) For detailed information, see section 6.6
TABLE OF CONTENTS

Table of contents ........................................................................................................... i
List of tables..................................................................................................................... iv
List of figures .................................................................................................................... vi
Acknowledgments ............................................................................................................ viii
Definitions and acronyms ............................................................................................... ix

1. Background .................................................................................................................. 1
   1.1 Difference between government and private analysis on the industry .................. 1
   1.2 Need to analyze the industry ................................................................................ 3
   1.3 Analysis of the industry with Lean Construction ................................................ 4

2. Problem statement ....................................................................................................... 6
   2.1 Research problem ................................................................................................... 6
      2.1.1 What is not known about the problem? ......................................................... 6
      2.1.2 Why does the problem matter? .................................................................... 8
   2.2 Research questions ............................................................................................... 9
   2.3 Research hypothesis ............................................................................................. 11

3. Literature review ......................................................................................................... 13
   3.1 What has been done in other nations? .................................................................. 13
      3.1.1 The USA (National Construction Goals, 1994) ........................................... 13
      3.1.2 Hong Kong (Tang Report, 2001) ................................................................. 14
      3.1.3 The UK (Egan’s report, 1998) ................................................................. 15
      3.1.4 Singapore (Construction 21, 1999) .............................................................. 17
      3.1.5 Australia (Building for growth, 1999) ......................................................... 19
      3.1.6 Japan ............................................................................................................. 20
      3.1.7 Korea ........................................................................................................... 22
      3.1.8 Comparison of change of the international market shares among nations ... 27
      3.1.9 International competitiveness of the Korean Construction Industry .......... 29
   3.2 Defining Lean Construction .................................................................................. 30
      3.2.1 Limits of the current indices of Lean Construction ....................................... 30
      3.2.2 Basic principles in measuring Lean Construction ......................................... 33
      3.2.3 Indicators of ‘Aligning goals toward project objectives’ .............................. 37
      3.2.4 Indicators of Value Stream Analysis and Set Based Design ....................... 40
      3.2.5 Indicators of production control (Last Planner™) ........................................ 43
   3.3 Defining project performance ............................................................................... 49

4. Research methodology ............................................................................................... 52
   4.1 Limits in view of internal validity .......................................................................... 52
   4.2 Combining quantitative and qualitative approach ............................................... 53
   4.3 Conceptualization and operationalization ............................................................. 57
   4.4 Validity and reliability of the measurement ......................................................... 62
   4.5 Sampling issues .................................................................................................... 63
   4.6 Finalizing research design .................................................................................... 76

5. Data collection and analysis ..................................................................................... 78
   5.1 Modification of survey at the beginning ............................................................. 78
      5.1.1 Face validation Test .................................................................................... 78
      5.1.2 During data collecting at the beginning .................................................... 80
5.2 First phase of data collection........................................................................................................ 81
  5.2.1. How to find members of Lean projects’ sample................................................................. 81
  5.2.2 Supplementary information collected in the first phase...................................................... 81
    5.2.2.1 Survey for an owner of a project separating design and construction ........ 81
    5.2.2.2 Survey for a contractor of a project separating design and construction .... 84
    5.2.2.3 Survey for an architect of a project separating design and construction ..... 87
    5.2.2.4 Survey for an owner of a project combining design and construction ...... 88
    5.2.2.5 Survey for a contractor of a project combining design and construction .... 91
    5.2.2.6 Conclusion of Chapter 5.2.2 ....................................................................................... 93
  5.2.3 Findings from the eleven projects in the first phase............................................................ 94
    5.2.3.1 Structure of scoring the eleven projects ................................................................. 94
    5.2.3.2 Statistical analysis using the eleven projects ............................................................ 94
    5.2.3.3 Result from the eleven projects with a restructured scoring .............................. 99
    5.2.3.4 Findings from the eleven projects ........................................................................... 100

5.3 The second phase of data collection.......................................................................................... 103
  5.3.1 How to find member of the Lean Construction Projects................................................... 103
  5.3.2 Structure of scoring the second phase projects ................................................................. 103
  5.3.3 Result of the survey in the second phase.......................................................................... 104
    5.3.4 Case study in the second phase ....................................................................................... 107
      5.3.4.1 Case selection strategy ......................................................................................... 107
      5.3.4.2 The first case ........................................................................................................ 110
      5.3.4.3 The second case ................................................................................................. 115
      5.3.4.4 The third case ...................................................................................................... 118
      5.3.4.5 The fourth case ................................................................................................. 121
      5.3.4.6 The fifth case ...................................................................................................... 124
      5.3.4.7 The sixth case .................................................................................................... 125
      5.3.4.8 Findings from case studies .................................................................................. 127

5.4 The third phase of data collection............................................................................................ 130
  5.4.1 Results of the survey in the third phase............................................................................ 130
    5.4.1.1 Performance and Lean Construction in the third phase ........................................ 130
    5.4.1.2 Performance and Incentive in the third phase ....................................................... 132
    5.4.1.3 Performance and Set Based Design in the third phase ........................................ 133
    5.4.1.4 Performance and Process Improvement in the third phase ................................ 134
    5.4.1.5 Performance and Last Planner™ in the third phase............................................... 135
  5.4.2 Conclusion in the third phase............................................................................................. 137
    5.4.2.1 Supplementary information from the third phase .................................................. 138

5.5 The fourth phase of data collection........................................................................................ 139
  5.5.1 Results of the fourth phase............................................................................................... 139
    5.5.1.1 Performance and Lean Construction in the fourth phase ....................................... 139
    5.5.1.2 Performance and Incentive in the fourth phase ....................................................... 145
    5.5.1.3 Performance and Process improvement in the fourth phase .................................. 145
    5.5.1.4 Performance and Last Planner™ in the fourth phase ............................................ 147
    5.5.1.5 Performance and Set Based Design in the fourth phase ....................................... 148
  5.5.2 Conclusion in the fourth phase.......................................................................................... 153
  5.5.3 Supplementary information collected in the fourth phase ............................................ 154
    5.5.3.1 Survey for the owners in the fourth phase .............................................................. 154
5.5.3.2 Survey for the architects of the project separating design and construction 156
5.5.3.3 Survey for the general contractors in the fourth phase ............................. 157
5.5.3.4 Conclusion about the supplementary information in the fourth phase ....... 160

6. Policy recommendation ............................................................................................... 162
   6.1 Recommendations for every project delivery system ........................................... 169
   6.2 Recommendations mainly for DB/ADB/TPB/and TC ............................................. 173
   6.3 Recommendations mainly for TPB based on schematic design ............................ 177
   6.4 Recommendations mainly for TPB based on detailed design ............................... 178
   6.5 Recommendations mainly for DB and ADB ......................................................... 179
   6.6 Recommendations mainly for ADB ................................................................. 182
   6.7 Recommendations mainly for TC ................................................................. 183
   6.8 Recommendations mainly for DBB ................................................................. 185

References ........................................................................................................................ 187

Appendix ............................................................................................................................ 193
   A.1. Limb 3 strategy ................................................................................................. 193
   A.2. Original version of the survey instrument ........................................................... 193
   A.3. Contents of the additional survey questioning constraint analysis ................... 199
   A.4. Interview for the first case on Oct. 25, 2010 .................................................... 199
   A.5. Interview for the second case on (Nov. 7, 2010) ............................................... 201
   A.6. Interview for the third case (Nov. 8, 2010) ....................................................... 205
   A.7. Interview with an anonymous contractor (Apr. 26, 2009) ................................. 205
   A.8. Interview for the sixth case on Nov. 9, 2010 ..................................................... 206
   A.9. Measurement of contractors’ participation in design in the third phase ............. 209
LIST OF TABLES

Table 1-1: Changes of indices in the Korean Construction Industry (MLTM, 2009) ...................... 1
Table 1-2: ENR’s market shares of nations in 2006 (MOCT, 2007-b) ............................................ 2
Table 1-3: Ways to develop the Korean Construction Industry (MLTM, 2009; MOCT, 2007-b) ....... 4
Table 2-1: The recommendations for the Korean public projects (Lee et al., 2003) ....................... 7
Table 2-2: Economic indices related to the Korean Construction Industry ................................. 8
Table 3-1: National Construction Goals of USA (Wright et al., 1995) ......................................... 13
Table 3-2: Main themes of Tang report (Tang, 2001) ................................................................. 14
Table 3-3: The main themes of Egan’s report (CTF, 1998) ....................................................... 16
Table 3-4: M4I project performance compared to all projects in 2001 (Egan, et al., 2002) .......... 16
Table 3-5: Main Contents of Construction 21 (Dulaimi et al., 2001) .......................................... 17
Table 3-6: Analysis of Variance on productivity change in Singapore ....................................... 18
Table 3-7: Japanese policy for the construction industry in 1995 (Shuwujou et al. 2007) .......... 21
Table 3-8: Construction policy guideline in MLIT (Shuwujou et al., 2007) ............................... 21
Table 3-9: Summary of Construction Vision 2020 (MCCI, 2009) ............................................. 24
Table 3-10: Comparison of construction cost among Nations (HanmiParsons et al., 2004) ....... 29
Table 3-11: Toyota Way’s 14 principles (Liker, 2004) .............................................................. 30
Table 3-12: Roadmap for implementing Lean projects (Ballard et al., 2007) ............................ 32
Table 3-13: Airplane Game’s principle (Ballard, 2007) ............................................................... 34
Table 3-14: Basic principles of Lean Construction ................................................................. 36
Table 3-15: The Australian national museum project’s criteria to select contractor (Allen et al., 2004) ...................................................... 39
Table 3-16: Main directions for VSA ....................................................................................... 40
Table 3-17: What should be determined in project planning (Ibbs, 2007) ............................... 43
Table 3-18: Examples of handoffs in a phase (Ballard et al., 2003) .......................................... 44
Table 3-19: List of constraints (Choo et al., 1999; Hamzeh et al., 2009) ............................... 45
Table 3-20: Quality criteria in a weekly work plan (Tommelein et al., 1997) .......................... 45
Table 3-21: Project performance indicators for this research ................................................... 49
Table 3-22: Comparison among the current Key Performance Indicators (KPI) ...................... 50
Table 4-1: Case selection description (Lieberman, 2005) ......................................................... 54
Table 4-2: Strategies for case study (Mahoney, 2000) .............................................................. 55
Table 4-3: Scoring according to type of answer ........................................................................ 58
Table 4-4: Classification of Korean construction projects .......................................................... 58
Table 4-5: Kinds of the contracts of Korean public construction projects ................................. 67
Table 4-6: Comparison between DBB and DB survey instrument ............................................ 73
Table 4-7: Kinds of current Project Delivery Systems (PDS) .................................................... 74
Table 5-1: Scoring structure in the first phase ......................................................................... 95
Table 5-2: Restructuring Last Planner™ scoring in the first phase ........................................... 99
Table 5-3: Scoring structure in the second phase ..................................................................... 101
Table 5-4: The basic statistics of Figure 5-24 ........................................................................... 106
Table 5-5: Main characteristics of the first case collected by additional questions ................. 110
Table 5-6: Main characteristics of the second case collected by additional questions .......... 115
Table 5-7: Main characteristics of the third case collected by additional questions ............... 118
Table 5-8: Brief of the fourth case ......................................................................................... 122
Table 5-9: Brief of the fifth case ............................................................................................ 124
Table 5-10: Brief of the sixth case .......................................................................................... 125
LIST OF FIGURES

Figure 2-1: Structure of research problem, research questions and research hypothesis ............... 12
Figure 3-1: Impact of a one-off productivity improvement (Hampson, 2005) ........................................ 20
Figure 3-2: Distribution of Korean public construction projects in 2008 (MCCI, 2009) ................... 26
Figure 3-3: International market share in construction from ENR (MLTM, 2009) ......................... 28
Figure 3-4: International market share in engineering from ENR (MLTM, 2009) ......................... 28
Figure 3-5: Lean Project Delivery System (Ballard, 2006) .............................................................. 41
Figure 3-6: Concepts and indicators of Lean Construction ............................................................... 48
Figure 4-1: Overview of the Nested Analysis Approach (Lieberman, 2005) ................................. 53
Figure 4-2: Case selection from a regression analysis (Lieberman, 2005) ................................. 54
Figure 4-3: Conceptualization and measurement (Adcock et al., 2001) ........................................ 57
Figure 4-4: Scoring structure of the survey for a Design-Build project’s owner ...................... 60
Figure 4-5: Scoring structure of the survey for a Design-Build project’s contractor ......... 61
Figure 4-6: Final research design ................................................................................................ 77
Figure 5-1: DBB/CM@R owners’ distrust in the contractors ......................................................... 82
Figure 5-2: DBB/CM@R owners’ recognition of problems in the procurement of contractor .... 82
Figure 5-3: DBB/CM@R owners’ recognition of performance as an absolute bid feature .... 83
Figure 5-4: Causes interfering performance improvement in view of DBB/CM@R owners ...... 83
Figure 5-5: DBB/CM@R/CM for fee’s contractors’ distrust in the owners ................................. 84
Figure 5-6: DBB/CM@R/CM for fee’s contractors’ recognition of problems in the current procurement of contractors ................................................. 85
Figure 5-7: DBB/CM@R/CM for fee’s contractors’ recognition of performance as an absolute bid criterion ................................................................. 85
Figure 5-8: Causes harming performance in view of DBB/CM@R/CM for fee’s contractor .... 86
Figure 5-9: DBB/CM@R/CM for fee architects’ distrust in the contractors ......................... 87
Figure 5-10: DBB/CM@R/CM for fee architects’ recognition of performance as an absolute bid criterion ................................................................. 87
Figure 5-11: Causes harming performance in view of DBB/CM@R/CM for fee architects .... 88
Figure 5-12: DB/EIC/IPD owners’ distrust in contractors ......................................................... 89
Figure 5-13: DB/EIC/IPD owners’ recognition of problems in the current procurement of Contractor ................................................................. 89
Figure 5-14: DB/EIC/IPD owners’ recognition of performance as an absolute bid criterion ...... 90
Figure 5-15: DB/EIC/IPD contractors’ distrust in the owner ...................................................... 91
Figure 5-16: DB/EIC/IPD contractors’ recognition of problems in the current procurement of Contractor ................................................................. 91
Figure 5-17: DB/EIC/IPD contractors’ recognition of performance as an absolute bid criterion ................................................................. 92
Figure 5-18: Causes harming performance in view of DB/EIC/IPD contractors ...................... 92
Figure 5-19: Regression line between performance and Lean Construction in the first phase .... 97
Figure 5-20: Regression line between performance and incentives in the first phase .......... 97
Figure 5-21: Regression line between performance and Set Based Design in the first phase .... 98
Figure 5-22: Regression line between performance and Last Planner™ in the first phase ...... 98
Figure 5-23: Regression line between performance and Last Planner™ based on Table 5-2 .... 100
Figure 5-24: Regression line between performance and Lean Construction in the second phase 105
Figure 5-25: Regression line between performance and Lean Construction in the third phase . 131
Figure 5-26: Regression line between performance and incentives in the third phase .......... 132
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I am deeply indebted to the dissertation committee members: Professor Herman Glenn Ballard, the dissertation advisor, guided this research from the start to the end and gave all his necessary knowledge for this research. Professor Iris D. Tommelein supported my work with her scientific knowledge of Lean Construction supply chain and with all relevant administration. Professor Laura Stoker guided most part of the research methodologies. Had it not been for her guide, this research would not have maintained creativity. Professor William Ibbs gave core knowledge of project management and supported with the precious reviewing on this paper.

I greatly appreciate the efforts and the consideration provided by the survey participants. Especially, Mr. Alan Mossman encouraged the members of the general IGLC discussion forum in the Yahoo group to participate in the survey. Had it not been for his help, this research would have had much less data and this would harm the research quality seriously. Also, many Korean specialists working for construction companies sacrificed their precious time to give data. Without their data, this research would not have diagnosed the Korean Construction Industry properly. I did not show the survey participants’ names for the protection of their privacy.

I greatly thank my wife, SoHee Kim, for her endurance, support, and loveable push toward her husband’s academic achievement. In fact, several beautiful presentations in this research paper were designed by her. I also thank Soomin Cho, my daughter, and Edward Cho, my son, for being the reason of life. They encouraged me to continue my work whenever I confronted difficulties in my life. In addition, I always thank God for having Hwui Kyung Cho, my father, and Ok Nam Kim, my mother, and Joo Won Kong, my grandmother, who have always prayed for their son and grandson’s happiness. I always feel sorry for not giving enough love to my parents and grandmother.

Finally, I deeply appreciate Korea, my lovable homeland country, who raised, educated, and helped me in countless ways in my whole life. I really want to repay what I owe to her.
### DEFINITIONS AND ACRONYMS

<table>
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<tr>
<th>Concept</th>
<th>Acronym</th>
<th>Definition</th>
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<tr>
<td>Limb 3 cost</td>
<td></td>
<td>This is a principle about distributing the difference between the actual cost and the target cost among the construction parties, which was employed by the British Petroleum in the early 1990’s. Limb 1 is the direct project cost and overhead, Limb 2(fees) is corporate overhead and profit, and Limb 3 is the predetermined pain share and gain share arrangement. Main decisions are made by the Project alliance board unanimously. At least, non owner participants (NOP) receive their direct cost (limb 1) and the burden which occurs after limb 2 is exhausted is up to the owner. As for distributing Limb 3, the difference between Limb 1 and target cost, Key Performance Indicator (KPI) is considered. If KPI is excellent, all the cost saving can be NOP’s, which is more than split of limb 3 fee. Otherwise, the opposite situation will occur (Sakal, 2005))</td>
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**Airplane Game**

Airplane Game assigns individual tasks to five production participants in order to make airplane LEGO block but it uses different principles to make the blocks at several rounds. The main purpose of Airplane Game is to compare the outputs among the different rounds. The first round employs none of Lean principles including 1) pull mechanism, which means working only when the next production unit requests an output; 2) distributed quality control; 3) minimized batch size; 4) pay based on team performance; and 5) optimized site working logistics. The second round only employs optimized site working logistics among the aforementioned 5 principles. The third round employs 1) optimized site working logistics; 2) pull mechanism; 3) minimized batch size; 4) limited quality control, in which the individual production units correct their own faults (while full quality control lets all participants be able to correct other workers’ faults). The fourth round adopts all five aforementioned principles. The first round usually recorded the worst productivity, the second round had a better productivity than the first round, the third round had a better productivity than the second round, and the fourth round had the best productivity (http://www.sefi.be/wp-content/abstracts/1092.pdf)

**Parade Game**

Similar to the Airplane Game, Parade Game varies production rates of individual trades delivering products (e.g., coins or bolts) as the stages are changed in order to
compare the overall productivity/inventory cost of the parade of the trades among the different stages. Parade Game shows that the biggest productivity happens when the production rates are evenly assigned among the trades and when there is no variability in assigning the production rates to trades. (http://www.ce.berkeley.edu/~tommelein/parade.htm)

<table>
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<tr>
<th>Last Planner™</th>
<th>LP</th>
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<td>It is a production control system mainly based on the reliability of weekly work plans. This system is comprised of the four different scheduling, which are a master schedule specifying the important milestones of an owner/main stakeholders, a Phase schedule addressing overall handoffs that a phase should produce, a Look-ahead process eliminating all possible constraints of a work before the execution of the work, and a weekly work plan investigating the quality criteria of a work right before the execution of the work. The degree of this production control system’s success is measured by the percentage of weekly planned works completed. (Hamzeh, F., 2009)</td>
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<th>Beer Game</th>
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<td>Beer Game is a role playing game describing beer (actually, small pennies in the game) delivery from beer factory to retailer. The players represent a retailer, a wholesaler, a distributor and a factory. The retailer orders beers from the wholesaler to meet customer’s demand, the wholesaler orders beers from the distributor to meet the retailer’s demand, the distributor orders beers from the factory to meet the wholesaler’s demand. Each week, each player tries to meet the downstream players’ orders. Any order, which cannot be met is a back order and should be met as soon as possible. It takes one week for an order to reach the upstream supplier and takes two weeks for the ordered beers to reach the downstream customer. Each week, each player is charged $1 per unit of backorder of beer and $0.5 per unit of inventory of beer. Each player cannot communicate each other directly. Information is delivered only through orders and shipments. Every player’s purpose is to minimize the total costs. Every simulation shows similar results. The amplitude of variance of orders steadily increases as the supply chain goes further upstream players (<a href="http://beergame.mit.edu/guide.htm">http://beergame.mit.edu/guide.htm</a>, and <a href="http://web.mit.edu/jsterman/www/SDG/beergame.html">http://web.mit.edu/jsterman/www/SDG/beergame.html</a>).</td>
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<tr>
<th>Value Stream Analysis</th>
<th>VSA</th>
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<td>After reviewing relevant literatures, I defined VSA as a series of the works analyzing all the processes in terms of creating value to the end customer and deleting or reducing the processes that do not create value or contain waiting</td>
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</table>
time. More specifically, VSA can include minimization of the batch sizes/management of the inventory/preassembly of the materials, standardization of the materials/processes, provision of instant communication channels between relevant processes and location of the materials requesting longer lead time at the earlier stage of the supply chain. (For references, see Table 3-16)

<table>
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<tr>
<th>Set Based Design</th>
<th>SBD</th>
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<td>SBD strategy urges all the relevant participants to collaborate in producing every possible design alternative and to collaborate all of them in analyzing if each alternative is feasible concurrently. The feasibility test should see if the alternatives are within constraints, including the target cost (duration) having been decomposed into the relevant components of the project. The inappropriate design alternatives that cannot pass the constraints should be deleted until the design team reaches the last responsible moment at which there is no longer sufficient lead time to realize other alternatives to the best fit design (Ballard, 2000-a).</td>
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<tr>
<th>Point Based Design</th>
<th>PBD</th>
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<tr>
<td>PBD is the concept right opposite to SBD. After some discussion, I defined PBD as the design in which each design specialist starts designing his/her part only after the previous specialists finished their design works.</td>
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<th>Work structuring</th>
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<tr>
<td>For easier understanding, it is to decide the contingency of a work’s duration, the resource storage’s size between consecutive works, the time buffer between works proportional to contingencies, and the batch size/exact conditions/production rate/prerequisites/sequences of the materials delivered between the relevant works. In Lean Construction, it is possible only while integrating product design and process design (quoted from the interviews with the expert group comprised of the relevant PhDs)</td>
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<tr>
<th>Design Bid Build with investigation of capability to build (of South Korea)</th>
<th>DBB with investigation of capability to build</th>
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<tbody>
<tr>
<td>This is the most prevalent form of a Korean DBB project. Instead of the DBB with competitive bidding based on the minimum price, this system uses the bid evaluation criteria including the capability to build such as financial credibility and the proximity of the bid price to a price determined by lottery system. Figure 6-6 describes the detailed process.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alternate Design Bid (of South Korea)</th>
<th>ADB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bidders submit an alternate design of the design provided by the owner as well as the two bid prices, one for the alternated design and the other for the original design. The owner will select his/her general contractor based on the bid (design) quality. Figure 6-4 describes the detailed</td>
<td></td>
</tr>
<tr>
<td>Technical Proposal Bid (of South Korea)</td>
<td>TPB</td>
</tr>
<tr>
<td>Enforcement Decree of the Act on Contracts to which the State is a Party</td>
<td>EDCSP</td>
</tr>
<tr>
<td>Construction Technology Management Act</td>
<td>CTMA</td>
</tr>
<tr>
<td>Central Construction Technology Deliberation Committee</td>
<td>CCTDC</td>
</tr>
</tbody>
</table>
CHAPTER 1: BACKGROUND

1.1 Differences between government and private analysis on the industry

The following Table 1-1 shows that Korean Construction Industry appears to be performing well. In line with that view, the Ministry of Construction and Transportation (MOCT)\(^2\) of Korea regards polarization\(^3\) among construction companies as the main problem (among other typical problems) of the industry (MOCT, 2007). However, Lee et al. (2003) indicates that the market competitiveness of the Korean Construction Industry is not good and the Korean government’s policy for lessening polarization among construction companies has reduced competitiveness. For example, Lee asserts that the increased number of contractors (3,896 in 1997, 12,461 in 2008; Construction Association of Korea web site: [http://www.cak.or.kr/](http://www.cak.or.kr/), 2008) is mainly due to the most common bid-awarding system for public projects, which tend to select contractor by chance to a certain degree in order to give more opportunities to small contractors.

Table 1-1: Changes of indices in the Korean Construction Industry (MLTM, 2009)

<table>
<thead>
<tr>
<th>Index</th>
<th>Past</th>
<th>Recent</th>
</tr>
</thead>
<tbody>
<tr>
<td>The international market share of Korea (construction)</td>
<td>2.3% (2002)</td>
<td>2.9% (2006)</td>
</tr>
<tr>
<td>The international market share of Korea (engineering)</td>
<td>0.04% (2002)</td>
<td>1.6% (2006)</td>
</tr>
<tr>
<td>Added value per person</td>
<td>29,500,000 Korean won (2002)(^4)</td>
<td>37,300,000 Korean Won (2006)</td>
</tr>
<tr>
<td>The number of persons killed in construction per 10,000 persons</td>
<td>2.4 (2002)</td>
<td>2.26 (2006)</td>
</tr>
<tr>
<td>The degree of technology compared to the world’s best level:</td>
<td>64% (1987)</td>
<td>77% (2007)</td>
</tr>
<tr>
<td>The total price of orders received from international markets</td>
<td>13.7 billion USD (1981)</td>
<td>47.6 billion USD (2008)</td>
</tr>
</tbody>
</table>

If we look at the Korean government’s statistics in more detail, we find features that might suggest Korean market competitiveness is fragile. 65.7% in 2006 and 56% in 2008 of the total export to the international construction markets was comprised of construction of Middle East plants (MCCI, 2009). This suggests a concern about what would happen if the specific field, Middle East plant construction, were used up. Also, the Korean trend of depending more on labor than technology can be seen in a simple comparison among nations vis-à-vis the international market share, which is found in the Engineering News Record (ENR) magazine. The Korean industry had a bigger portion (2.9%) in the pure international construction market than that (1.9%) of the engineering market in 2006.

\(^2\) Ministry of Construction and Transportation of Korea (MOCT) changed its name to Ministry of Land, Transport, and Marine Affairs (MLTM) on Feb. 29, 2008

\(^3\) Polarization refers to the difference of average total sales between big companies and small companies. And there is clear definition about the size of a company (the 21,368\(^{th}\) presidential decree revised on Mar. 25, 2009).

However, in the USA, one of the most competent nations in the industry, the engineering market share (42.1%) is much bigger than that (17.1%) of pure construction.

More generally, it seems that the more advanced a nation is in construction technology, the bigger its market share is in engineering unlike Korea. Table 1-2 shows that several supporting examples. The USA and the UK, regarded as advanced nations, take 17.1% and 5.2% in world construction production respectively. Their sharing in the global engineering market is much bigger than that of Korea.

<table>
<thead>
<tr>
<th>Pure Construction Market</th>
<th>Engineering Market</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Total world production in construction is 100%)</td>
<td>(Total world production in engineering is 100%)</td>
</tr>
<tr>
<td>USA: 17.1%</td>
<td>USA: 42.1%</td>
</tr>
<tr>
<td>France: 15%</td>
<td>UK: 12%</td>
</tr>
<tr>
<td>Germany: 11.5%</td>
<td>Netherlands: 10.5%</td>
</tr>
<tr>
<td>Japan: 8.4%</td>
<td>Canada: 9.3%</td>
</tr>
<tr>
<td>China: 7.3%</td>
<td>Japan: 2.8%</td>
</tr>
<tr>
<td>UK: 5.2%</td>
<td>South Korea: 2.9%</td>
</tr>
<tr>
<td>South Korea: 2.9%</td>
<td>South Korea: 1.9%</td>
</tr>
</tbody>
</table>

Yoon et al. (2005) also assert that there has not been enough recognition of the importance of project feasibility and project design in Korean domestic construction, so that many construction projects that underwent severe cost/schedule overruns or functional defects have been produced without relevant analysis such as economic feasibility study. To justify his assertion, Yoon cited a table which compared the unit costs of buildings. In that table, the average unit cost of a building (apartment, office building and hospital) of the Korean Construction Industry was over 130% that of the UK’s industry, while the cost of the USA’s building was around 90% of the UK’s cost5. In addition, Yoon pointed out that due to the protective government policy, the size of the Korean domestic construction has annually increased by 5~10%.

A review of the literature shows a certain degree of difference in analyzing the industry between government reports and private research. While lessening polarization is one of the main concerns of the government, private research indicates that there is a structural problem in maintaining market competitiveness. The question, of which one is better, has been the motivation of this research.

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5 This cost comparison can be debatable. HanmiParsons et al. (2004) found that Korean construction unit cost is much cheaper than the USA's unit cost.
1.2 Need to analyze the industry

As Lee et al. (2003)⁶ mentioned, if the main bid-awarding system of public projects is not able to select the best qualified contractors, most contractors do not feel obligated to realize the best performance of public projects but only try to increase the probability of winning a bid. The most popular bid-awarding system in Korea has been selecting contractors based on chance to a certain degree.⁷ A company can create several paper companies with different names and let them participate in the bidding, to increase the probability of winning the bid. This selection method does not encourage contractors to enhance their competitiveness because it is not necessary (Lee et al., 2003; MOCT, 2007-a).

Table 1-3 includes several solutions to the aforementioned problems such as its items 2 (improvement of the criteria for assessing the capability to build), 6 (creation of a more cooperative atmosphere for the mutual successes among construction parties) and 9 (enforcement of post evaluation of performance after completion of a project).

In another government report (MOCT, 2007-c), which provides more detail on the item 6 of Table 1-3, we find nothing about modifying the bid-awarding process and only about enhancing the communication among participants in a project, which causes confusion about whether the purpose of item 6 is to produce better performance or just communication itself. As for item 2, it should be strong enough to discard any unqualified contractors in the prequalification test if the intention is to raise the level of competitiveness in the industry. If there are elements in the current prequalification or screening process that gives small contractors more opportunities to win a bid just because they are small, without serious consideration about real capability, then item 2 in Table 1-3 should be designed to eliminate those existing elements. This recommendation was produced in 2007. However, similar problems were pointed out in 2009. According to MCCI (2009), prequalification screening has not worked properly, so that dozens of contractors submitting bids for a project could pass the test, and the awards by ‘investigation of capacity to build’ have been determined by chance to a certain degree.

Likewise, the result of item 9, ‘Enforcement of post evaluation of performance after completion of a project’, should be used in the bidding process for future projects, and contractors who had produced undesirable performance in prior projects should be prohibited from participating in next projects, or else provide evidence that there would be no possibility for them to produce similar undesirable performance. Item 9 in Table 1-3 is somewhat realized in the 69th provision of the Enforcement Decree of the Construction Technology Management Act requiring that an owner (government agency) make a post-evaluation report of a project if the total cost of the project is over 50 million Korean won in order to make standard duration or cost of a construction processes.

In conclusion, Korean policy has tried to enhance the industry’s competitiveness, but it is not clear whether the trials have been strong enough. Thus, this research aims to clarify by diagnosing the current status of the industry and by investigating the appropriateness of government policy as a tool for curing whatever is found to be a problem from this research. Another purpose of this research can be to see which attitude is correct:

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⁶ His critique was followed by construction vision 2020 (MCCI, 2009), which will be discussed later. He was one of chairs of the movement.

⁷ In this system, the owner investigates the bid prices’ proximity to the 88% of the estimated price. The estimated price is determined by a lottery system at the bidding time. That is why we call this system a ‘selection by chance.’ Of course, there are other items for measuring the capability to build but the investigation of bid price takes a relatively big portion. (Korean Government accounting regulation 2200.04-149-23.2009.4.8).
The government agency says that there is enough national competitiveness in the industry and that we should lessen the polarization, but the private sector encourages to increase competitiveness (Lee et al., 2003).

Table 1-3: Ways to develop the Korean Construction Industry (MLTM, 2009; MOCT, 2007-b)

<table>
<thead>
<tr>
<th></th>
<th>Improvement of the criteria for registration and classification of types of construction business.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Improvement of criteria for assessing the capability to build.</td>
</tr>
<tr>
<td>3</td>
<td>Introduction of the Construction Management at Risk (CM@R) contract.</td>
</tr>
<tr>
<td>4</td>
<td>Allowing more flexibility in selecting contractors for public construction projects.</td>
</tr>
<tr>
<td>5</td>
<td>Advancement of construction surety or assurance policy.</td>
</tr>
<tr>
<td>6</td>
<td>Creation of a more cooperative atmosphere for the mutual successes among construction parties.</td>
</tr>
<tr>
<td>7</td>
<td>Nurturing and training highly technical human resources and suppliers of materials.</td>
</tr>
<tr>
<td>8</td>
<td>Establishment of a constant monitoring system of the total process of a construction project.</td>
</tr>
<tr>
<td>9</td>
<td>Enforcement of post evaluation of performance after completion of a project.</td>
</tr>
<tr>
<td>10</td>
<td>Enforcing the assessment and usage of R&amp;D.</td>
</tr>
<tr>
<td>11</td>
<td>More reasonable operation of Design-Build and Alternate Design-Bid.</td>
</tr>
<tr>
<td>12</td>
<td>Encouraging IT usage.</td>
</tr>
</tbody>
</table>

1.3 Analysis of the industry with Lean Construction

The Lean Construction ideal, to be ever more closely approximated, is to provide a custom product exactly fit for purpose, delivered instantly, with no waste, using the best available tools under appropriate principles (Ballard et al., 2007). Continuous improvement, a pursuit of perfection, is at the heart of Lean Construction.

The average performance of a contractor can show the degree of competitiveness of the contractor in the market because the average performance reflects the satisfaction degree measured by the customer group; and based on the customer group’s degree of satisfaction the contractor receiving the highest rating will have a relative advantage over those who get lower ratings from the customer group. The relative advantage in the market is the degree of competitiveness in the market.
In brief, pursuing Lean Construction means seeking better performance and seeking better performance means having higher market competitiveness. Thus, in principle, pursuing Lean Construction leads to better market competitiveness than otherwise. Moreover, if the theory of Lean Construction explains how to achieve better market competitiveness, it is possible to describe the degree of average competitiveness of the Korean Construction Industry and to suggest how to improve it.

The inferences mentioned above spurred me to start this research, which would diagnose the Korean construction industry and make recommendations based on Lean Construction theory in order to find ways to improve the nation’s competitiveness.
CHAPTER 2: PROBLEM STATEMENT

2.1 Research problem

A research problem is an issue or concern that needs to be addressed (Crenswell, 2003). So far, I reviewed briefly the current state of the Korean Construction Industry in Chapter 1. Even though there have been many attempts to improve the industry, if some reduce competitiveness, it could bring long-term damage to the industry, such as degradation of performance of constructed products. This can be a serious threat to the end users’ life or can result in a loss of jobs in the markets when the market becomes open to international contractors, which is one of trends of the global economy. Thus, my research problem is “How can we increase the competitiveness of the Korean Construction Industry with methods that have not been used so far, such as Lean Construction?”

2.1.1 What is not known about the problem?

As I showed, Table 1-3 summarized the Korean government’s basic policies in 2007 to improve the industry. Even though Table 1-3 contains overall fields needed to develop the industry, there have been critiques about current policies regarding competitiveness. Alternatives have been produced by both the public sector and private sector.

MOCT (2007-a) defined polarization as one of the main problems and, in order to lessen it, suggested creating a mood for cooperation among construction parties for the mutual successes of all construction parties by implanting a team-based decision-making system into public projects, enhancing long-term partnering practices between parties, overseeing the process for general contractors to deal with subcontractors and establishing a constant monitoring system to dismiss unqualified contractors. In order to see if these suggestions work well, the Korean government agency initiated several pilot projects. Thus, it will be valuable to check if these pilot projects achieved better performance and to what degree they have implemented management principles based on Lean Construction.

Some private research pointed directly to the current bid-awarding system or the project delivery system as the main culprits hindering competitiveness. For example, Lee et al. (2003) asserts that contractor-procurement systems in public projects, such as 1) bidding with the investigation of capability to build, 2) minimum price bidding, and 3) the design-build delivery system, and the process for estimation of prices in public projects have serious problems in terms of market competitiveness, as presented in Table 2-1.

Several research projects coming from the public sector and private sector have produced their own diagnoses and recommendations. The interesting difference between those two sectors is that government reports put more emphasis on lessening polarization among construction companies than private research does. So, it would be valuable to analyze the current overall conditions of the industry, which have been driven mainly by the government, regarding competitiveness. Then, we can judge which recommendations are more desirable for the current conditions.
Table 2-1: The recommendations for the Korean public projects (Lee et al., 2003)

<table>
<thead>
<tr>
<th>Current practice</th>
<th>Problems and tentative recommendation</th>
<th>Recommendation</th>
</tr>
</thead>
</table>
| Minimum price bidding, with investigation of the appropriateness of capability to build | ① Most bidders would pass the investigation (Lacking screening capability)  
② Final pre-arranged price is determined by luck, so that the selection of the final contractor, the person who submitted the nearest price to the pre-arranged price, is determined by chance (Lacking capability to select the most competent bidder)  
③ Paper companies or unqualified companies made for increasing probability to win a bid | Making the criteria of investigation more strict |
| Minimum price bidding | It considers only price, regardless of capability, quality of past experiences, or Life cycle or time factor so that an incompetent contractor can be selected if he/she submitted the lowest price (Lacking the power of distinguishing) | Making use of various quality evaluations in bidding |
| Design-Build | ① Overlapping Design and Building is not possible (Lacking fast track)  
② Deliberation by third parties could produce illegal lobbies and waste time | Study more to find out appropriate form of delivery system |
| Estimation of cost in public projects before bidding | The standardized unit process, which has been reference in making estimated/pre-arranged prices of public projects, have been exaggerated by having allowed the association of contractors to participate in producing them (Lacking reality. That if contractors make owner’s prices, they probably inflate the cost for their future benefit is the main point) | Making use of historical data per agencies |
| Long-term contract, more than a year | No guarantee about annual budget but only about lump-sum cost of a project with a same contractor bringing about delay, cost variation due to the uncertainty | Contracting with continuous annual budget of a long-term project with a same contractor |

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8 In fact, this has been made possible by the 62nd provision of the enforcement decree of the Construction Technology Management Act. Remember that Lee’s work was done in 2003.  
9 In fact, this has been made possible by the 9th provision of the Enforcement Decree of the Act on Contracts to which the State is a Party.
2.1.2 Why does the problem matter?

Judging from Table 2-2, a high percentage of GDP is invested in the Korean Construction Industry, which means that the impact on the overall economy, represented as employment and exports, is that much greater. According to a press release of the Construction & Economy Research Institute of Korea on March 19, 2010, this percentage of investment in the Korean Construction Industry is predicted to decrease to about 11% in 2020, based on the analysis of other advanced nations’ (www.cerik.re.kr). Table 2-2 also shows that, for every one million dollars invested, 16.3 persons were employed in the Construction Industry in 2009 while that amount of investment created only 8.6 employees in the Manufacturing Industry in 2008. Further, employment in construction was 7.7% of total employment of Korea in 2008, while construction was 11.3% of overall Korean exports in the same year. In short, the role of the construction industry in the nation’s economy is very considerable. If there is a structural problem in maintaining the competitiveness of the Industry, the problem will directly damage the economy of Korea.

Table 2-2: Economic indices related to the Korean Construction Industry

| The ratio of investment into the construction industry in the Korean GDP | 18.4% in 2004, 18.0% in 2005, 17.7% in 2006, 17.5% in 2007, 18.0% in 2008, and 18.4% in 2009 (CAK, 2009) |
| The Leontief multiplier of the Korean Construction Industry | 1.980 (CAK, 2009) |
| The Leontief multiplier of the Korean Manufacturing Industry | 1.972 (CAK, 2009) |
| Employment in the Korean Construction Industry (1,000Won=1 USD) | 16.3 person/1 million dollars (CAK, 2009) |
| Employment in the Korean Manufacturing Industry | 8.6 person/1 million dollars (Lee et al., 2008) |
| The ratio of the construction employment to the total Korean employment | 7.7% (2008), 7.9% (2007) |
| The ratio of the manufacturing employment to total Korean employment | 17.6% (2007), 16.8% (2008) |
| The contribution of the Construction Industry to Korean national export | 5.1% (06), 10.7% (07), and 11.3% (2008) (CAK, 2009) |
2.2. Research questions

After deciding the research problem, we should develop research questions to be answered in order to solve the problem. The questions should not be too narrow or too broad (Handley et al., 2009). Thus, this research developed the questions as follows:

[Q 1] Has Lean Construction enhanced the performance of projects?

This is a really important question. If there is no concrete evidence that Lean Construction improved the performance of past projects that adopted it, the strategy to adopt Lean Construction as a tool to enhance the competitiveness of the Korean Construction Industry is useless. This question sought the answers to the prior concern and the answer was found in those projects outside Korea that have already employed Lean Construction.

[Q 2] Does the Korean Construction Industry lack implementation of Lean Construction?

Assuming that the answer to the first research question is positive, if the degree of implementation of Lean Construction in the Korean Construction Industry is low, we can easily guess that there could be problems in the industry in terms of competitiveness. There are several representative tools, methods or principles, which were discussed later in Chapter 3, in Lean Construction. This research question sought to what extent the Korean Construction Industry used those tools, methods or principles.

[Q 3] Is the performance of Korean construction projects worse than that in those that employed Lean Construction?

If the answers to the first and second research questions are positive, the performance of Korean construction should be worse than those projects implementing Lean Construction more. Thus, this research question could be used in the triangulation to check if the first question and the second question are appropriately set and measured.\(^\text{10}\)

The regression model between Lean implementation and project performance created in answering the first question can be used to quantify the loss in performance of Korean construction examined in the second question, assuming the same measurements are used in both questions.\(^\text{11}\)

Some studies showed that Lean Construction might not be the result of independent factors but rather a kind of gestalt, such that one factor may be ineffective in the absence of the other factors. If so, simply counting up the number of Lean practices might not provide a good measure of Lean implementation. In that case, a deepened qualitative research is more appropriate than supporting hypothesis testing with quantification. This issue was discussed in more detail in the research methodology chapter (Chapter 4).

[Q 4] What recommendations can be made to increase the competitiveness of the Korean Construction Industry?

\(^\text{10}\) Triangulation strengthens a study by combining methods. This includes using several kinds of methods or data in both quantitative and qualitative approaches (Patton 2002, p 247).

\(^\text{11}\) In fact, research design includes modification of measurement based on intermediate results and the performance indicators were different between Korean projects and Lean projects, which lead me not to compare performance between the two groups. This issue was discussed in the Chapter 4, Research Methodology.
From the results of investigation of [Q] 1, 2 and 3, I evaluated the current policies and practices regarding their impact on national competitiveness. In addition, the current recommendations or legal policies made by the Korean governments were interpreted in terms of Lean Construction. Similarly, many other nations, such as Hong Kong, the UK and Singapore, have promoted innovative movements to develop their construction industry based on the diagnoses of their current policies. However, whether or not each recommendation made by [Q 4] is valid is beyond the range of this research. The purpose of the fourth question is to reinterpret the current Korean practices with the theoretical tools and analytical results developed in [Q] 1, 2 and 3. The validation of each recommendation can be ascertained by future research.

However, I can provide the recommendations with some belief through the investigation of other nations’ movements related to construction innovation. In fact, some nations, such as the UK, Hong Kong and Singapore, have tried to raise their national competitiveness in the industry. Their recommendations have been proven to be successful and to implement Lean Construction to a high degree, which was addressed in Chapter 3.1 and also gave me assurance that the recommendations made by this research are on the correct path.

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12 The chapter 3.1 addressed several national movements innovating on the construction industry including the Korean movement.
13 HongKong’s Tang Report, UK’s Rethinking Construction, and Singapore’s Construction 21 were the movements.
2.3 Research hypothesis

To answer the research questions in section 2.2, I set “The implementation of Lean Construction improves the performance of construction projects.” as the research hypothesis that this thesis should support. The reasoning behind this hypothesis is explained as follows:

[Q 1 and hypothesis: [Q1] is “Has Lean Construction enhanced the performance of projects?” If the research hypothesis is correct, the answer to [Q1] is “yes.” If not, the answer is “No”. The hypothesis testing for [Q1] was performed on Lean Projects chosen selectively among those that were known to have employed Lean Construction because if I had selected projects randomly, most of the respondents would have not produced meaningful survey results due to lack of knowledge about Lean Construction. The detailed strategy of the hypothesis testing was discussed in Chapter 4.

[Q 2 and 3] hypothesis: [Q2] is “Does the Korean Construction Industry lack implementation of Lean Construction?” The measurement of the independent variable of the hypothesis that was tested on the randomly chosen Korean projects determines the answer to [Q2]. Similarly, [Q3] is “Is the performance of Korean construction projects worse than that in those that employed Lean Construction?” The measurement of the dependent variable of the hypothesis tested on the Korean sample determines the answer to [Q3].

Especially, [Q3] needed comparison of performance between Korean projects and Lean projects. The dependent variable of the hypothesis tested on the Lean projects for [Q1] should have been compared to the dependent variable of [Q3]’s hypothesis to answer [Q3] correctly. However, the measurements of the dependent variables could not be identical to each other due to the severe contractual difference between the Korean projects and the Lean projects. Thus, the answer to [Q3] came to be a diagnostic result of Korean project performance rather a comparison between the two groups. The detailed process how to measure variables of the hypotheses is addressed through Chapter 5.

Assuming that the research hypothesis is true, we can easily expect that the degree of implementing Lean Construction in Korea is relatively low because Lean Construction is a strange thing to most parties in the nation’s industry. Consequently, we can expect the performance of the industry is not so desirable due to the low degree of Leanness.

[Q 4 and hypothesis: [Q4] is “What recommendations can be made to increase competitiveness of the Korean Construction Industry?” As for [Q4], I produced policy recommendations based on the answers to [Q1], [Q2] and [Q3]. The relevant Korean regulations are the target of the recommendations. I investigated the current Project Delivery Systems (PDSs) specified in the regulations and evaluated them in terms of Lean Construction. Finally, I suggested how to improve the PDSs. The detailed recommendations are addressed in Chapter 6.

There are three basic Acts related to the Korean Construction Industry, which are the target of analysis for [Q 4]. They are responsible for most parts of the construction policies including PDSs, contract types, registration of construction jobs, subcontracting, bonds and surety issues and technology development. Thus, the recommendations, answers to [Q4], are based on these three Acts. The relations between research problems, questions and hypotheses are described in Figure 2-1.

14 The Act on Contracts to which the State is a Party, the Construction Technology Management Act, and the Framework Act on the Construction Industry (http://likms.assembly.go.kr/law/).
<Research Problem>
How can we increase the competitiveness of the Korean Construction Industry with the methods which have not been used so far such as Lean Construction?

{Research question #1}
Has Lean construction enhanced performance of projects?

Hypothesis testing on the projects which already adopted Lean Construction (Purposive sampling outside Korea)

{Research question #2}
Does the Korean Construction Industry lack the implementation of Lean Construction?

Measuring the independent variable of the Hypothesis (Random sampling from Korean projects)

{Research question #3}
Is the performance of Korean Construction projects worse than those that adopted Lean Construction?

Measuring the dependent variable of the Hypothesis (Random sampling from Korean projects)

{Research question #4}
Can we make recommendations in order to raise the level of competitiveness of the Korean Construction Industry?

Reinterpret the current construction policies with the measurement of independent variable and make modified versions of the policies

[Research Hypothesis]
The implementation of Lean Construction will increase the performance of construction projects

Figure 2-1: The structure of research problem, research questions and research hypothesis
CHAPTER 3: LITERATURE REVIEW

3.1 What has been done in other nations?

3.1.1 The USA (National Construction Goals, 1994)

The National Science and Technology Council (NSTC) was established by an executive order of the Clinton Administration in Nov. 1993. The primary goal of the NSTC is the establishment of clear goals for Federal Science and Technology investment (Wright et al., 1995). The NCG and its vision were defined in a 1995 report produced by a subcommittee of the Civilian Industrial Technology Committee, itself a subcommittee of the NSTC (Table 3-1).

Table 3-1: National Construction Goals of USA (Wright et al., 1995)

<table>
<thead>
<tr>
<th>Non-technical Barriers of USA’s Construction Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Lack of Leadership</td>
</tr>
<tr>
<td>3) Regulatory Barriers</td>
</tr>
<tr>
<td>5) Lack of Liability</td>
</tr>
<tr>
<td>2) Adversarial Relations</td>
</tr>
<tr>
<td>4) Financial Disincentives</td>
</tr>
<tr>
<td>6) Scarcity of Skilled Labor</td>
</tr>
</tbody>
</table>

The vision of National Construction Goals (NCG)

1) High quality constructed facilities support the competitiveness of the USA’s industry and everyone’s quality of life.
2) The USA’s industry leads in quality and economy in the global market for construction products and services.
3) The construction industry and constructed facilities are energy efficient, environmentally benign, safe and healthful, properly responsive to human needs, and sustainable in use of resources.
4) Natural and manmade hazards do not cause disasters.

NCG

1) 50% reduction in delivery time
2) 50% reduction in operation, maintenance, and energy costs
3) 30% increase in productivity and comfort
4) 50% fewer occupant related illnesses and injuries
5) 50% less waste and pollution
6) 50% more durability and flexibility
7) 50% reduction in construction work-related illnesses and injuries.

From Table 3-1, the NCG’s vision is to maximize market competitiveness of the construction industry and to minimize environmental and safety risks. To realize this vision, NCG sets very definite performance goals, such as reduction of time, cost and accidents. Compared to the strategy of the Korean Construction Industry, which is also concerned about solving the problem of polarization, NCG attacked the incompetency in a more direct way. NCG also declared the eight major products for achieving goals, which were 1) leadership for innovation, 2) regulatory reinvention, 3) skilled construction work force, 4) base lines and measures progress, 5) human factors, 6) information system, 7) high performance materials and systems and 8) automation. (Wright et al., 1995)
Although we cannot say the NCG is the only factor lifting the construction industry of the USA up to today’s No. 1 rank, the NCG must have contributed to it. Table 1-2 (p. 2) shows that the USA’s construction companies’ international construction market share is 17% (Korea: 2.9%) in 2006 and the USA ranked No.1 as well in the engineering market; that of the USA in the international engineering market share took 42.1% (Korea: 1.9%).

Most of the technical barriers in Table 3-1 cause disintegration of information, which is a main culprit of disturbing work flows. Maintaining reliable work flows is one of the basic production theories to reduce waste (Koskela 2000, and Ballard et al., 2003). On the basis of this interpretation, reinterpreting other nations’ successful innovative movements with the lens of Lean Construction can give us more justification for this research.

3.1.2 Hong Kong (Tang report, 2001)

Table 3-2: Main themes of Tang report (Tang, 2001)

<table>
<thead>
<tr>
<th>Problems</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tendency to make non-value-adding multi-layered subcontracts.</td>
<td></td>
</tr>
<tr>
<td>Highly fragmented structure with adversarial culture among participants.</td>
<td></td>
</tr>
<tr>
<td>Labor-intensive construction methods rather than ones using advanced technologies.</td>
<td></td>
</tr>
<tr>
<td>Inadequately trained work forces.</td>
<td></td>
</tr>
<tr>
<td>Unsatisfactory quality in terms of time, cost and high accident rates.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vision</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>To develop an integrated construction industry that is capable of continuous improvements toward excellence in a market-driven environment.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Recommendations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>To establish the culture for quality, there needs to be a proactive client, a voluntary subcontractor registration scheme, site supervision for elimination of non-value-adding and multi-layered subcontracts.</td>
<td></td>
</tr>
<tr>
<td>To create more value in procurement, there needs to be more consideration about performance in terms of cost and quality in the selection of contractors, partnering and alignment of interests among participants, equitable risk allocations, better resolution of disputes, and equitable payment systems.</td>
<td></td>
</tr>
<tr>
<td>To nurture professional work forces, the industry needs to take ‘soft’ skills and multi-disciplinary approach, to set a prerequisite course for professional membership renewal, to provide formalized trainings for supervisory-level staff, to enforce a registration scheme for workers, and to use direct labor.</td>
<td></td>
</tr>
<tr>
<td>To enhance efficiency, innovation and productivity, it is necessary to raise the level of safety and environmental performance, to set an institutional frame work, to encourage the government to be the best practice client and a facilitating regulator, to encourage industry to have the culture of continuous development and to surpass clients’ expectations, to encourage to use of IT, to expand R&amp;D, and to build underground information.</td>
<td></td>
</tr>
<tr>
<td>To make work places safer, the industry needs to benchmark other nations’ economies, to introduce hazard management performed by all the participants, to introduce safety promotion and training at all levels.</td>
<td></td>
</tr>
</tbody>
</table>
To make the industry more environmentally friendly, there needs to be focus on lifecycle costing, greener and more energy-efficient design, regular impact assessments on the cumulative impact of environmental legislation, and waste management.

Hong Kong’s construction industry has had problems described in Table 3-2. These problems are similar to those of the Korean Industry. However, even though both Korea and Hong Kong illustrate that the highly fragmented and adversarial culture among construction parties is a problem, the intentions are different in each context. The adversarial culture reduces the end users’ value in view of the Tang report, while the same culture is a manifestation of a biased distribution of profits among construction parties in the Korean government’s view.

We can see this difference in the vision and recommendations of the Tang report. This report led to some improvements. According to Wong (2007), the accident rate decreased from 149/1000 in 2000 to 64/1000 in 2006, the number of prosecutions decreased from 770 in 2000 to 72 in 2006 and overall construction waste decreased by 25% at all disposal facilities.

Hong Kong’s vision is to make the best market-friendly construction industry through integration. The purpose of integration is to produce more value for customers. Thus, their recommendations for realizing the vision suggest creating more value, better quality, better efficiency and safer and more sustainable environments.

In conclusion, the main themes of the Tang report are summarized to integrate the industry more, to create more customer value, and to adopt the best practices; and these features are coincident with Lean Construction, which was discussed in more detail in section 3.2. In fact, Tang Report’s strategy has been believed to enhance the overall quality of the nation’s industry, which is supported by research. Based on Hong Kong’s case, I could expect that recommendation based on Lean Construction should improve the Korean Construction Industry to a certain degree.

3.1.3 The UK (Egan’s report, 1998)

Table 3-3 summarizes Egan’s Report. Similar to the NCG of the USA, the goals of this report are focused on enhancing market competitiveness. The reason to cite ‘too highly fragmentized industry’ as a problem is that the UK acknowledged that fragmentation disturbs the continuous improvement of performance, similar to Tang Report. The difference between Korea and the UK or Hong Kong is the degree to which they focus more on the customers’ side.

According to the ENR international ranking, the UK’s share in the construction market decreased from 7.9% in 2002 to 5.2% in 2006, but the share in the engineering market increased from 6.7% in 1998 to 12% in 2006. Although it is not clear that the increase of market share in engineering is due to Egan’s innovation, I can only say that the engineering needing more technological aspects than construction must have been influenced by the UK’s innovation in some way.

The UK government has operated the strategic forum for construction, one of whose assignments has been to check achievements of Rethinking Construction spurred by Egan’s report. According to a public release from the strategic forum for construction in 2002, they initiated pilot projects under the name of Movement For Innovation (M4I), which recorded remarkable performance compared to normal construction projects. Table 3-4 is the summary of their achievements showing Rethinking Construction implementation achieved better performance in almost all aspects.
### Table 3-3: The main themes of Egan’s report (CTF, 1998)

#### Problems

1) Dissatisfaction of customers (about 1/3)  
2) Too highly fragmentized industry (the number of small contractors, whose number of employees is than 8: 163,000)  
3) Repeated process (about 80%)  
4) Wasted manpower (about 40%)

#### Solutions

1) More committed leadership  
2) Attitudes focusing more on customers  
3) Attitudes focusing more on an integrated process  
4) Attitudes focusing more on a quality-driven agenda

#### Specific Goals

1) 10% annual reduction of cost  
2) 20% annual reduction of accidents and defects  
3) 10% annual increase in productivity  
4) 10% annual increase at turnover and profits

UK Project performance has improved continuously since M4I projects were initiated. The annual report 2004/2005 of the strategic forum for construction showed 20% of projects (by value) were undertaken by integrated teams and there was clear evidence that the greater was the integration, the greater were the benefits achieved. Eighty percent of the owners, having embraced, ‘client charter’ specifying best practices based on Rethinking Construction, agreed to take ‘client charter’ again due to the benefits, and more skilled workforces have been recruited than expected due to the demand for sustainable innovation (Strategic forum for construction, 2005).

### Table 3-4: M4I project performance compared to all projects in 2001 (Egan et al., 2002)

<table>
<thead>
<tr>
<th>Key performance Indicator</th>
<th>Measure</th>
<th>All Construction</th>
<th>M4I</th>
<th>M4I Enhancement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client Satisfaction-Product</td>
<td>Scoring 8/10 or better</td>
<td>73%</td>
<td>85%</td>
<td>+16%</td>
</tr>
<tr>
<td>Client Satisfaction – Service</td>
<td>Scoring 8/10 or better</td>
<td>65%</td>
<td>80%</td>
<td>+23%</td>
</tr>
<tr>
<td>Defects</td>
<td>Scoring 8/10 or better</td>
<td>58%</td>
<td>86%</td>
<td>+48%</td>
</tr>
<tr>
<td>Safety</td>
<td>Mean Accident incidence rate /100K employed</td>
<td>990</td>
<td>495</td>
<td>+100%</td>
</tr>
<tr>
<td>Profitability</td>
<td>Median profit on turnover</td>
<td>5.6%</td>
<td>7.6%</td>
<td>+2%</td>
</tr>
<tr>
<td>Productivity</td>
<td>Median value added/employee (£000)</td>
<td>28</td>
<td>34</td>
<td>+21%</td>
</tr>
<tr>
<td>Cost</td>
<td>Change compared to 1 year ago</td>
<td>+2%</td>
<td>-2%</td>
<td>+4%</td>
</tr>
<tr>
<td>Time</td>
<td>Change compared to 1 year ago</td>
<td>+4%</td>
<td>-8%</td>
<td>+12%</td>
</tr>
</tbody>
</table>
In conclusion, UK construction innovation implemented recommendations to increase market competitiveness and the implementation achieved significant results, which confirms the validity of the direction of this research.

3.1.4 Singapore (Construction 21, 1999)

Table 3-5 summarizes the Construction 21 report, the master plan of the Singapore government for innovation of the construction industry. Singapore investigated developed nations’ situations in order to make the report. As a result, the recommendations take on the form directed to increase market competitiveness with other nations. Another interesting thing is that Singapore anticipated the adoption of Lean Construction as one of the future trends (Dulaimi et al., 2001). Therefore, investigating the trend of Singapore’s construction industry since 1999 could give further insight into the possibility of success of a government-driven movement adopting Lean Construction.

Table 3-5: Main contents of Construction 21 (Dulaimi et al., 2001)

<table>
<thead>
<tr>
<th>Problems</th>
<th>What is needed for more development</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Low productivity growth rate – 4.6% ~ -3.4% (1995~1998)</td>
<td>1) Highly skilled indigenous work forces</td>
</tr>
<tr>
<td>2) Labor intensive and low-skilled industry rather than knowledge-based industry</td>
<td>2) Strong interest in developing human resources</td>
</tr>
<tr>
<td>3) Segregated activities</td>
<td>3) Professionalized construction companies through licensing</td>
</tr>
<tr>
<td>4) Heavy reliance on poorly skilled foreign workers</td>
<td>4) Efforts to enhance productivity and competitiveness</td>
</tr>
</tbody>
</table>

Na (2006) quotes statistics of Building Construction Authority to show the current status of the Singapore’s Construction Industry, in which the labor productivity change rate has been maintained as minus numbers since 1995. Even though the numbers are minus, there is a difference before and after 1999, when Construction 21 was launched. The average of percentage change in labor productivity from 1996 to 1999\textsuperscript{15} is -4.75% and one from 2000 to 2003 is -1.15%.

\textsuperscript{15} Specific numbers: -3.8% in 1996, -4.8% in 1997, -5.7% in 1998, -4.7% in 1999, -2.5% in 2000, -0.6% in 2001, -1.0% in 2002, and -0.5% in 2003
Table 3-6 investigates whether the difference of the percentage changes’ mean is significant, using Analysis of Variance test in STATA v.10. There are two groups: from 1993 to 1999 and from 2000 to 2003. ‘Sum of squares in between groups’ is the portion of productivity change’s variance, which can be explained by the grouping. ‘Sum of squares within groups’ is the portion that cannot be explained by the grouping. ‘Mean square’ is the value of ‘Sum of squares’ divided by the relevant ‘degree of freedom.’ F is the ratio of the ‘Mean square.’ The Mean square between groups is the numerator of the ratio. If the probability > F is less than 0.05, the grouping has significant influence on the productivity change rates.

The ‘Bartlett’s test’ in Table 3-6 for equal variance shows we cannot reject the null hypothesis that the two groups have equal variance. If Probability > chi (2) in Bartlett’s test is less than 0.05, we can reject the null hypothesis, which says that the results of Analysis of Variance are not reliable. This does not happen in Table 3-6. The reason to check Bartlett’s test is because the equal variance within group is an important assumption of an ANOVA test.

The conclusion here is that there is a significantly positive difference of the mean of construction productivity change rate in Singapore before and after the Construction 21 movement, which included Lean Construction as a main tool to renovate the nation’s construction industry.

Table 3-6: Analysis of Variance on productivity change in Singapore

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Degree of Freedom</th>
<th>Mean Squares</th>
<th>F</th>
<th>Probability &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>25.92</td>
<td>1</td>
<td>25.92</td>
<td>35.51</td>
<td>0.0010</td>
</tr>
<tr>
<td>Within Groups</td>
<td>4.38</td>
<td>6</td>
<td>.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>30.30</td>
<td>7</td>
<td>4.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bartlett's test for equal variances</td>
<td>chi2(1) = 0.079</td>
<td>Probability &gt; Chi2 =0.78</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eight annual productivity change (the detail of the cases analyzed)</td>
<td>-3.8% in 1996</td>
<td>-4.8% in 1997</td>
<td>-5.7% in 1998</td>
<td>-4.7% in 1999</td>
<td>-2.5% in 2000</td>
</tr>
<tr>
<td></td>
<td>-0.6% in 2001</td>
<td>-1.0% in 2002</td>
<td>-0.5% in 2003</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.1.5 Australia (Building for Growth, 1999)

This is a set of 35 recommendations made by the National Building and Construction Committee established by the Australian government. According to this report, the percentage of the Australian Construction Industry in the GDP was 14%, the industry had a highly fragmented structure in which 230,000 firms hired 750,000 workers (94% of businesses employ less than 5 persons), the percentage of R&D investment in the GDP was only 0.04 (Japan has 0.45 as the investment percentage, Finland has 0.21) (McCarthy, 2003).16

The main contents of the 35 recommendations are: 1) more frequent industrial surveys; 2) increased communications among government agencies; 3) increased R&D investments and applications; 4) expanded IT usage including electric bidding system; 5) an additional research center named as Cooperative Research Center (CRC); 6) integrated processes among construction parties; 7) launched pilot projects and 8) enlarged international market by governments (National Building and Construction Committee, 1999).

Compared to those of Hong Kong, the USA, the UK and Singapore, the Australian recommendations required government aids to the industry rather than encouraging the industry to renovate itself in order to attain better market competitiveness. They seemed to reflect the voice of providers rather than the voice of customers (e.g., industry surveys done by government, launching pilot projects done by government, research center established by government to find a better way to improve the industry and more R&D invested by government).

The movement, which Building for Growth headed, has been transferred to Construction 2020, an advanced form of construction innovation made in 2004. Construction 2020 report was made by the research center, CRC, which Building for Growth had planned. The nine visions of Construction 2020 are: 1) environmentally sustainable construction; 2) meeting client needs; 3) improved business environment; 4) welfare and improvement of the labor force; 5) information and communication technologies for construction; 6) virtual prototyping for design, manufacture and operation; 7) off-site manufacturing; 8) improved process of manufacture and construction product; and 9) Australian leadership in research and innovation (Hampson et al., 2004). At least, 2), 5), 6), 7), and 8) seem to be relevant to Lean Construction, which emphasizes creating the best customer value, instant communication between supplier and customer in construction processes, and process improvement thorough standardization of process/design or preassembly. The detailed contents of Lean Construction are addressed throughout section 3.2.

The CRC for Construction, which has driven the Australian innovation, suggested a graph, Figure 3-1, showing that an 10% increase of construction productivity could bring positive change in Gross State Production, with a steeper increase rate than other one-off production sectors such as public production (administration, defense, health, etc.), retail and accommodation, and business service as time goes.

In conclusion, the Australian government has pursued construction innovations partly relevant to Lean Construction, based on research to prove that the innovation would improve overall productivity in construction and that improvement would also enhance the overall economy of the nation. I hope that their achievement will be shown in concrete statistics in the near future.

16 These statistics seem to be those in 2003 rather than 1999 when the recommendations were made because the data in 1999 said that the portion of construction in GDP was 6.2% and there were 138,000 relevant businesses according to Wang, et al. (1999).
3.1.6 Japan

The crash of the ‘Bubble Economy’ greatly decreased the total money invested in the Japanese Construction Industry, from 84,000 billion Yen in 1992 to 51,900 billion Yen in 2004. In spite of this decrease, the number of construction companies increased from less than 5.5 million in 1992 to 5.59 million in 2004. This abundance of providers led to severe polarization in terms of the average total sales per company (Shuwujou et al., 2007).

The ministry of Land, Infrastructure, Transport, and Tourism of Japan (MLIT) promulgated a policy for the construction industry in April 1995. Table 3-7 summarizes the contents. At least the fourth item in the Basic directions in Table 3-7 seems to lessen the polarization between middle-small companies and the larger companies, but it is not clear that the item is intended to give small companies more chances to win bids only because they are small companies.\(^{17}\)

However, the basic guideline policy of MLIT to revive the Japanese Construction Industry in 2003 focused more on raising the level of competitiveness of the industry rather than reducing the degree of polarization among companies. This policy encouraged construction companies to focus on their specialized fields where they could achieve their best competitiveness and recommended that they reduce costs, improve quality, and develop new products or methods (Shuwujou et al., 2007).

\(^{17}\) The Korean public sector’s owners can give more incentives in awarding bids to contractors if they make a consortium with small companies. Certain kinds of Korean projects sometimes require only small companies to participate in the bids (Lee et al., 2003).
Table 3-7: Japanese policy for the construction industry in 1995 (Shuwujou et al. 2007)

<table>
<thead>
<tr>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>To produce better performance at lower cost in order to revive confidence in the industry</td>
</tr>
<tr>
<td>Problems recognized by MLIT</td>
</tr>
</tbody>
</table>
| 1) Abrupt increase in the number of middle-layer contractors  
2) Highly stratified industry  
3) Insufficiency of skilled labor force  
4) Small share of the international market as a problem of the industry |  
| Basic directions for improvement |  
| 1) Excluding unqualified or unethical contractors  
2) Clarifying the financial rewards in the engineering fields  
3) Making a framework for desirable activities of enterprises  
4) Making a basis to develop middle and small companies  
5) Improvement of quality  
6) Developing human resources and IT applications  
7) Supporting the trial of construction companies to develop themselves |  

This movement to enhance the level of competitiveness was continued by the next policy-making group, the forum for studying construction policy, organized by MLIT in 2006. Its vision and guidelines are summarized in Table 3-8. The Japanese government agency recognized that today’s manufacturing should turn its back on the mass production and mass consumption theory to meet the current demands represented by small consumption, for more varied kinds of production and use of collaborative team work, theory consistent with native Japanese culture, instead of the Western adversarial and competitive culture among industrial participants (METI, 2005).

Table 3-8: Construction policy guideline in MLIT (Shuwujou et al., 2007)

<table>
<thead>
<tr>
<th>Visions</th>
</tr>
</thead>
</table>
| 1) Realizing Value for money to end user through appropriate competition  
2) Collaboration with all the participants having equal rights in delivery of projects. |  
| Guidelines |  
| 1) Establishing fair relations among participants in the legal system  
2) Innovations in bidding and contracting  
3) Guaranteeing that construction projects are performed by qualified technical work forces |  

This recognition shows that the Japanese government started thinking about how to create the basis for the industries to be more sensitive to the customers’ demands, which coincides with the Lean Ideal.\(^\text{18}\)

\(^{18}\) If a project is attempting to provide a custom product exactly fit for the purpose, delivered instantly, with no waste, the project can be said to pursue the Lean Ideal (Ballard et al., 2007).
In fact, according to the table named C.7., which was quoted by the Committee on Advancing the Competitiveness and Productivity of the USA’s Construction Industry, National Research Council (CACPC, 2009) and compared construction productivity among nations, Japanese construction productivity, -0.06, was better than the USA’s, -0.84, in terms of average annual growth rate from 1979 to 2003. CACPC (2009) also regarded Japan as one of the nations in which construction innovative movements are pursued more actively than in other nations. Of course, the growth rate of construction productivity is not a perfect index to indicate the level of competitiveness. For example, the absolute value of construction productivity of the USA was near the top, while the UK took 20%, Sweden 76%, Norway 56%, France 46%, and Belgium 62% of the USA’s construction productivity (CACPC, 2009).

In conclusion, Japan has pursued innovation of construction to increase its national competitiveness and its achievements have been acknowledged by other nations, such as the USA, that have tried for similar goals.

3.1.7 Korea

MLTM of Korea held a conference on Jan. 22, 2009 to hear the various opinions about the Vision 2020, a policy report for improving the construction industry. In contrast to past policies, this policy suggestion focused on raising the level of competitiveness. The main items are summarized in Table 3-9.

Construction Vision 2020 is comprised of one vision, three targets and five strategies that have sub strategies. Many parts try to adopt construction traditions used in the UK or the USA that has sought strategies to increase national competitiveness, as mentioned earlier. However, some recommendations do not seem to be appropriate in terms of Lean Construction. For example,

(a) The recommendation in a) of the first item of <Strategy 1>, ‘Removing the circulative human resource management for guaranteeing more liability of a public project’, should be deleted or modified in a way that the government gives the responsive civil servants more specific and direct incentives/disincentives to get more reliable outcomes of public projects. The circulative and periodic job allocations in the Korean government agencies has been justified for preventing corruptions caused by a government officer who takes a same position too long. Before making big changes in the current system as this recommendation suggests, we need to consider how the system reaches this point. Circulative human resource management in the public sector should be regarded as a proper constraint, which contractors should consider when they make plans or schedules. A public project’s owner might be a relevant civil servant in government. Producers’ requests to customers (government agencies or civil servants) to change the customers’ system, having been established for a long time based on rationale, would not have a strong power to persuade without appropriate and urgent reasons.

(b) The recommendation in g) of the third item of <strategy 1>, ‘Selecting contractors based on bidding documents defining the detail amounts and unit prices of materials according to the design/specification made by owners’, will produce additional wasteful processes done by the selected contractor to recalculate real quantities of materials during construction in Lean Construction’s view. Lean Construction asserts that more detailed quantities of works or material, specified in the contract before removing all constraints of that work, is more
vulnerable to changes as the execution of that work approaches. This recommendation in Vision 2020 is nothing more than seeing if the contractor submitting a bid is able to calculate detailed prices from the design that the owner agency provided, even though that design may be lacking reality or constructability.

(c) The recommendation in the fourth item of <strategy 5>, ‘Removing the barriers among works relevant to construction’, doesn’t seem to support today’s market trend demanding high-level specialization and ignores the current registration policy for construction jobs supporting the trend. This also contradicts another recommendation, the first item of <strategy 2>, encouraging the industry to be highly specialized. For a detailed explanation of this recommendation, Construction Vision 2020 (MCCI, 2009) advised eliminating the registration process of construction works because the criteria of registering are too high for competitive individuals or companies to enter. In addition, it advised eliminating the job classification between general contractor and specialty contractor. Every job needs a certain level of professionalism or proficiency in that field. Registering specific jobs helps maintain certain professional levels in the industry. For example, the current Act requires a general contractor to have 5-12 specialized engineers and to have at least 1.2 billion Korean won as capital (MCCI, 2009). These conditions can prevent competitive companies, which lack capital or engineers, from being general contractors. In fact, Korean relevant Acts put unnecessarily big weight on business management status or financial credibility, where bigger companies can easily get better scores, in investigation of bidders’ capability to build in public Design-Bid-Build projects.

In a similar sense, MCCI (2009) pointed out that an owner does not need a bidder’s financial credibility/business management information scored by Credit Information Companies if bond systems perform properly. However, the amount of project cost has been a very important factor in determining Korean project delivery systems or contracting strategies. For example, 30 billion Korean won is the criteria, whether a project takes a Design-Build or a Design-Bid-Build (the 79th provision of the Enforcement Decree of the Act on Contracts to which the State is a Party). Thus, the eligibility to be the general contractor of a project might be the capital size that a contractor candidate is capable of building. If there is uncertainty in the owner’s funding, it is very important for a contractor to have the financial capability to finish the project in a more reliable way. However, we need to give an appropriate weight to the financial ability of a bidder.

I do not agree with removing the registration of construction works nor the separate classifications between general contractor and specialty contractor. If a specialty contractor wants to do a job that only a registered general contractor can do, the only thing he/she has to do is to qualify to be registered as a general contractor. However, if representing him/herself as a specialty contractor, a member of a consortium, is more advantageous to be awarded a bid, then, he/she can participate as a specialty contractor in the bid. More important thing is whether the criteria of the registration of a work properly reflect qualification for the work in the real world.

19 Predicting and removing constraints before execution is the essence of Last Planner™, which Lean Construction takes as production control methodology. This feature will be discussed in more detail later in this literature review chapter.

20 The Public Accounting established rule (2200.04-149-26, revised September 8, 2010) the purpose of which is to specify how to investigate bidders’ capability to build according to the 42nd provision of the Enforcement Decree of the Act on Contracts to which the State is a Party.
The list suggested as global standard of project delivery/contracting system in the third item of <strategy 1> needs more consideration about the current project delivery system and plan reliability. For example, Construction Management @ Risk (CM@R) would confuse which part is responsible for project performance in the public sector. The government agency is entrusted with responsibility of public projects. If it uses CM@R, the government agency should pay the CM additional money for taking a portion of their responsibility, which is not easily understood by the nation’s people, who have entrusted the project to the government including responsibility for the performance. MCCI (2009) asserted that the lack of special knowledge of the government agents needs CM@R in public sector, which does not acknowledge technical authority and capability of the government organization responsible for the specific technical part. Before taking CM@R as a public project delivery system, we need to set the limit of outsourcing in the public sector. Even though we adopt it as a public project delivery system, there can be a lot of room for legal conflicts over who is responsible for a project’s outcome being worse than expected. To prepare the case, both the government agency and CM must be equipped with perfect contractual documents, from the beginning, to make the situation more favorable to each.21 That is the adversarial relationship among project parties that Lean Construction tries to remove in order to reduce waste.

Darrington et al. (2010) also pointed out similar problems in Guaranteed Maximum Price (GMP) contracting usually used with CM@R, in which CM tries to do change orders to cope with unexpected conditions lest he/she should take the legal risk of cost overrun, or to inflate the GMP to acquire a safe margin. In addition, subcontracted works under GMP contracts tend to do change orders, or to recoup the money lost by claims, all of which might be caused by competitive biddings for the subcontracted works.

However, the third master plan for developing the Korean Construction Industry, promulgated by the Ministry of Land, Transport and Marine affairs, planned to introduce CM@R into public projects (MCCI, 2009). My recommendation is that Korean society needs to identify the problem that caused Korean industry to think of CM@R as a solution first and considers how to eliminate the root cause instead of taking CM@R as a superficial medication.

Table 3-9: Summary of Construction Vision 2020 (MCCI, 2009)

<table>
<thead>
<tr>
<th>Vision</th>
<th>Creating Global Value Industry trusted by people</th>
</tr>
</thead>
<tbody>
<tr>
<td>Targets</td>
<td>1. Reduction of construction costs by 30%</td>
</tr>
<tr>
<td></td>
<td>2. Achieving the total amount of international orders in construction, up to 200 billion dollars</td>
</tr>
<tr>
<td></td>
<td>3. Ranking Korea within 10th place counted from the top seat in transparency</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>&lt;Strategy 1&gt;</th>
<th>Innovation of public project’s ordering system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Increasing public owner’s capability and enforcing responsibility</td>
</tr>
<tr>
<td></td>
<td>a) Removing the circulative human resource management for guaranteeing more liability of a public project</td>
</tr>
<tr>
<td></td>
<td>b) Educating public officers in order for them to get core knowledge</td>
</tr>
<tr>
<td></td>
<td>c) Finding and disseminating best practices</td>
</tr>
<tr>
<td></td>
<td>d) Making and disseminating owner’s manuals</td>
</tr>
<tr>
<td></td>
<td>e) Making certificate program for qualified owner</td>
</tr>
</tbody>
</table>

---

21 Those, disagreeing with using CM@R in public sector, are the opinions of the author of this dissertation based on the job experience in the ministry of Land, Transport, and Marine affairs.
2. Strengthening public owner’s independence and discretion in determining project delivery systems.

3. Bringing global standards into project delivery and contracting system:
   a) Introducing new methods of selecting contractors such as CM at risk, program management, fixed price contracting, contracting by roughly estimated price, selecting considering the converted price of reduction of duration (A+B contracting), and Guaranteed Maximum Price contracting.
   b) Design to cost and cost management for Building.
   c) Early involvement of designer and enforcement of the communication between design and building.
   d) Making it mandatory to take continuous price contracting (with annual budget promise) for long term projects longer than 1 year.
   e) Enforcing the screening power of Pre-Qualification test.
   f) Using the synthetic assessment considering price and technical aspects at the same time in selecting contractors by minimum price bidding
   g) Selecting contractors based on bidding documents defining the detail amounts and unit prices of materials according to the design/specification made by owners

4. Acquiring productivity and safety at global level: Process/organization innovation, safety through design, and so on

5. Enforcing performance management of public project: Developing and operating Key Performance Indicators, and making Post-project evaluation effective in order to find best practices

<table>
<thead>
<tr>
<th>&lt;Strategy 2&gt;</th>
<th>Global competitiveness of designing and engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fostering global level engineering firms and making engineering more specialized: using quality based selection in procuring engineering firms, bringing global standards into design/engineering criteria and product, rearing small but specialized engineering firms, and so on.</td>
<td></td>
</tr>
<tr>
<td>2. Establishing Design Governance, which is comprised of owner, designer, contractor, and interest parties, from start to finish, in order to create best-value building structure</td>
<td></td>
</tr>
<tr>
<td>3. Simplifying the diversified government administrations relevant to engineering works/certificates.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>&lt;Strategy 3&gt;</th>
<th>Support for small companies and enforcement of cooperation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Support for small companies to go abroad through financial aid</td>
<td></td>
</tr>
<tr>
<td>2. Innovation of relation between big and small companies: encouraging partnering based on a project, or many projects; and using prime contract rather than subcontracting</td>
<td></td>
</tr>
<tr>
<td>3. Eliminating unfair traditions in subcontracting</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>&lt;Strategy 4&gt;</th>
<th>Enhancing transparency and elimination of corruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Normalizing the design deliberation/consulting of the Turnkey/Alternate Design project through appropriate operation of deliberation committee</td>
<td></td>
</tr>
<tr>
<td>2. Making relevant information during construction process, including bid evaluation and post-measured performance, open and transparent</td>
<td></td>
</tr>
<tr>
<td>3. Using an effective but fair punishment system</td>
<td></td>
</tr>
</tbody>
</table>

22 Many long term projects make contracts without annual budget plan according to the 69th provision of the Enforcement Decree of the Act on Contracts to which the State is a Party
<Strategy 5>

Establishing Knowledge base for the world best industry

1. Innovating construction technology through Research and Development (R&D)
2. Management of R&D operation based on performance
3. Encouraging partnership between big and small companies in R&D
4. Removing the barriers among works relevant to construction
5. Making bonds (surety, performance and bid) more effective

In summary, even though Construction Vision 2020 was created to increase the competitiveness of the construction industry, it lacks enough consideration of project reliability or the current legal system. Thus, this research will produce policy recommendations more fit to Lean Construction, focusing on increasing plan reliability, and to the current legal system, rather than relying on the current policy recommendation, such as Construction Vision 2020.

The following chart is quoted from the reference data in Construction Vision 2020, which divides all the public projects contracted in 2008 according to project delivery systems and contracting methods. The money represents only what general contractors were awarded. Minimum price bidding and Bidding with investigation of capability to build belong to Design-Bid-Build projects, which comprise 68% of all public projects. Judging from this chart, the Design-Bid-Build, a representative of the disintegrated project delivery system, is the dominant project delivery system in Korean public sector, which encourages this researcher to produce policy recommendations in terms of Lean Construction, which regards integration of design and construction as the first condition toward best performance.

![Distribution of Korean public construction projects in 2008 (MCCI, 2009)](image)

Figure 3-2: Distribution of Korean public construction projects in 2008 (MCCI, 2009)
3.1.8 Comparison of changes in the international market shares among nations

There is interesting data in MLTM (2009) summarizing trends in international market share in the construction and engineering fields of some nations. MLTM (2009) made this data based on ENR publications. Figure 3-3 and 3-4 are the graphic representations of these trends. From these figures, there seems to be no significant problem in the Korean construction industry. Some features are found: 1) China has increased the shares continuously; 2) the USA has maintained the top seats since 1997; 3) Japan underwent a serious decrease in its shares in 1995; and 4) the USA’s share in Engineering is much bigger than that in Construction in recent years. A similar trend to the USA’s is also found in the UK. The UK’s share in the international construction market was 5.3% in 2006 but its share in engineering markets was 12.2% at the same time. As we saw in 3.1.1 and 3.1.3, NCG of the USA and Rethinking Construction of the UK pursued market competitiveness in the innovation of their construction industries. To speak frankly, the appearances of NCG and Rethinking Construction are similar to that of Lean Construction such as removing regulatory barriers, financial incentives, removing adversarial relationships, developing more committed leadership, attitudes focusing more on customers, attitudes focusing more on integrated processes, and attitudes focusing more on a quality-driven agenda. The direction of their movement at that time could be related to the current high sharing percentages in the international market. These trends can be powerful indices, telling the results of government innovation for the industry based on increasing competitiveness.

Another factor we should consider is the proportion of industry investment in the nation’s GDP. The bigger portion means more influence, caused by the industry, on the economy. As we saw in Table 2-2, South Korea invests a high percentage of its GDP in construction. According to a press release from the Construction & Economy Research Institute of Korea (CERIK) on Mar. 19, 2010, the Korean percent will likely decrease to 11-to-11.5% in 2020 based on the trend of the construction sector in other advanced nations. Based on the CERIK’s analysis, we can guess abnormally bigger money has been poured into the Korean Construction Industry and if there are factors causing inefficiency in the industry, the nation’s overall economy might have a big problem. Again, this researcher’s purpose is to diagnose the overall construction industry of South Korea in view of Lean Construction, which is believed to increase competitiveness by bringing more customer value with less waste.

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23 See http://www.cerik.re.kr/
Figure 3-3: International market share in construction from ENR (MLTM, 2009)

Figure 3-4: International market share in engineering from ENR (MLTM, 2009)
3.1.9 International competitiveness of the Korean Construction industry

HanmiParsons et al. (2008) compared costs, durations, and productivity per day among Korea, Japan, the UK, and the USA construction projects through case studies. Costs included pure costs, net profits, and overall overhead costs. Duration means the time from the beginning to the end of a project. The comparison was done based on the Purchasing Power Parity (PPP) exchange rate, which considered the purchasing power of each currency. The result is described in Table 3-10, which shows the USA’s cost of constructing a regular office building was 162% of that of a Korean office building, the UK’s cost was 160% and Japan’s cost was 90%.

Moreover, HanmiParsons et al. (2008) did comparisons of the construction cost of a four-lane expressway and in the construction duration of an office building. The Korean cost of the expressway is 20.7 billion won/km, while the Japanese cost is 19.86 billion won/km, similar to that of the USA’s, and the UK’s cost is 24.7 billion won. Also, the duration of the USA’s construction of an office building per floor is 12.8 days, while Japanese duration is 24.1 days and Korean duration is 31.3 days.

However, this cost comparison can be debatable because there are other reports showing different results. As we saw earlier, Yoon et al. (2005) said that the average unit cost of a building (apartment, office building or hospital) of the Korean Construction Industry is over 130% of the UK’s building cost, while the USA’s is around 90% of the UK’s. Considering the aforementioned studies, it is hard to compare the market competitiveness among nations using only unit construction cost. I tried to address the market competitiveness of the Korean construction industry in this thesis but could not make any conclusion because I came to use different performance indicators between Korea and the other nations due to the different situation between the two groups.

Table 3-10: Comparison of construction cost among nations (HanmiParsons et al., 2004)

<table>
<thead>
<tr>
<th></th>
<th>Korea</th>
<th>The USA</th>
<th>The UK</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation and Structure</td>
<td>282,244</td>
<td>318,288</td>
<td>372,608</td>
<td>252,634</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>113%</td>
<td>132%</td>
<td>90%</td>
</tr>
<tr>
<td>Carcase</td>
<td>943,872</td>
<td>1,602,072</td>
<td>1,563,041</td>
<td>908,335</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>170%</td>
<td>166%</td>
<td>96%</td>
</tr>
<tr>
<td>Finishing</td>
<td>474,541</td>
<td>788,626</td>
<td>865,641</td>
<td>424,927</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>166%</td>
<td>182%</td>
<td>90%</td>
</tr>
<tr>
<td>Furniture and Fittings</td>
<td>100,439</td>
<td>175,103</td>
<td>136,144</td>
<td>119,334</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>174%</td>
<td>136%</td>
<td>119%</td>
</tr>
<tr>
<td>Services</td>
<td>1,500,589</td>
<td>2,458,161</td>
<td>2,019,080</td>
<td>1,139,409</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>164%</td>
<td>135%</td>
<td>76%</td>
</tr>
<tr>
<td>Miscellaneous works</td>
<td>23,947</td>
<td>46,513</td>
<td>28,070</td>
<td>26,164</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>194%</td>
<td>117%</td>
<td>109%</td>
</tr>
<tr>
<td>Preliminaries</td>
<td>334,630</td>
<td>532,955</td>
<td>879,632</td>
<td>428971</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>159%</td>
<td>263%</td>
<td>128%</td>
</tr>
<tr>
<td>Cost(Won)/3.3m²</td>
<td>3,660,000</td>
<td>5,921,000</td>
<td>5,865,000</td>
<td>3299000</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>162%</td>
<td>160%</td>
<td>90%</td>
</tr>
</tbody>
</table>
3.2 Defining Lean Construction

3.2.1 Limits of the current indices of Lean Construction

‘Implementation of Lean Construction in a project will enhance the project performance’ is the hypothesis, which this thesis tests. To test this hypothesis, first of all, this research must define what implementation of Lean Construction means and what project performance means. Concrete definition of causal and resultant components of a hypothesis, independent variable and dependent variable of the hypothesis, respectively, is directly related to the measurement of the variables. Thus, this chapter is devoted to a review of literature concerning the definition of Lean Construction, the independent variable.

The first example of Lean Construction is the 14 Toyota Way (Liker, 2004) according to Ballard et al. (2007)’s assertion that the 14 Toyota Way principles (Table 3-11) should be the main principles in the implementation of Lean Construction. The next task is to investigate if the items in Table 3-11 are appropriate as systemized concepts or indicators\(^{24}\) of the independent variable of this research.

Table 3-11: 14 Toyota Way’s 14 principles (Liker, 2004)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Base decision on long-term philosophy even at the expense of short term financial goals.</td>
</tr>
<tr>
<td>2.</td>
<td>Create continuous process flow to bring problems to the surface.</td>
</tr>
<tr>
<td>3.</td>
<td>Use ‘Pull’ systems to avoid over production.</td>
</tr>
<tr>
<td>4.</td>
<td>Level out workload – work like the tortoise, not the hare.</td>
</tr>
<tr>
<td>5.</td>
<td>Build a culture of stopping to fix problems to get the quality right the first time.</td>
</tr>
<tr>
<td>6.</td>
<td>Standardized tasks are the foundation for continuous improvement and employee empowerment.</td>
</tr>
<tr>
<td>7.</td>
<td>Use visual control, so no problems are hidden.</td>
</tr>
<tr>
<td>8.</td>
<td>Use only reliable, thoroughly tested technology that serves people and processes.</td>
</tr>
<tr>
<td>9.</td>
<td>Develop leaders who thoroughly understand the work, live the philosophy, and teach it to others.</td>
</tr>
<tr>
<td>10.</td>
<td>Develop exceptional people and teams who follow your company’s philosophy.</td>
</tr>
<tr>
<td>11.</td>
<td>Respect your extended network of partners and suppliers by challenging them and helping them improve.</td>
</tr>
<tr>
<td>12.</td>
<td>Go and see for yourself to thoroughly understand the situation.</td>
</tr>
<tr>
<td>13.</td>
<td>Make decisions slowly by consensus, thoroughly considering all options; implement rapidly.</td>
</tr>
</tbody>
</table>

\(^{24}\) Systemized concepts are specified and diversified sub-divisions of an abstract variable such as the degree of implementation of Lean Construction in order to address the variable more concretely. Indicators are sub-items of a systemized concept in order to measure the systemized concept in the form of a numerical score. The detailed explanation is in Chapter 4, Research methodology.
There could be some problems if this research directly uses the items in Table 3-11 as the systemized concepts for the independent variable of this research. One problem is abstractness. Some abstract words in the above principles would make the measurement very hard. For example, the 1st principle contains the phrases ‘long-term philosophy’ and ‘short-term financial goal,’ which are difficult to measure; the 11th principle may involve questions such as “How to respect partners and suppliers?” and “How can we measure the degree of respect?” The 12th principle can raise questions such as “Who is ‘you’? Are they customers, contractors, or suppliers?” or “To what degree should we go and see for ourselves? Should we go and see only at important junctures in the process or should we check on every finite task?” Another problem is the interdependency among principles. For example, the exceptional people in the 10th principle can be leaders in the 9th principle. The interdependency can create the problem of multicollinearity\textsuperscript{25} in analyzing through statistical methods such as a regression analysis.

The second example trying to define Lean Construction is the Lean Principles suggested by Womack & Jones (1996),\textsuperscript{26} which consist of: 1) specifying value from the standpoint of the end customer; 2) identifying all steps in the value stream for each product family and eliminating whatever steps that do not create value; 3) taking value-creating steps so that the product will flow smoothly toward the customer; 4) letting customers’ pull value from the next upstream activity; and 5) continuing 1) to 4) until a state of perfection is reached. However, these principles are criticized for lacking tangibility and the abstractness in measurement (Hofacker et al., 2008). As an alternative, Hofacker et al. (2008) suggested a rapid Lean Construction–Quality Rating model (LCR), which can be assessed by participatory observation at construction sites. I came to conclude that this rating system also has some problems, in that rating should be done only by close observation. It can only measure the movements in a construction site without investigation of contracting or designing, and it has no clear explanation between the relation of rating and performance.

The next example is the ‘Roadmap for implementing Lean Projects,’ defined by Ballard et al. (2007) in Table 3-12 that seems to include almost everything to implement Lean Construction at the project level, but the problem is the usefulness in measurement. Some difficulties in using the Roadmap directly as concepts/indicators for this research include the followings.

(a) Table 3-12 has some features that can be regarded as traditional construction management technologies, not unique indicators of Lean Construction. For example, most feasibility studies produce the project scopes as the means and investigate the feasibility of the scopes based on constraint analysis. We need to extract significantly different features of Lean construction from other general feasibility studies to measure Lean Construction appropriately. As for target costing in Lean Construction, some persons can ask a question, “What is the difference between our minimum price bidding and target costing? We produce the lowest price by competition but target costing produces the lowest price by collaboration. That is just about how to produce the lowest price. Am I wrong?” Thus, we need to extract the unique features explaining Lean Construction’s target cost compared to the traditional method.

\textsuperscript{25} In multicollinearity, none of the independent variables significantly predict well the dependent variables even though the overall model fits the data well (Motulsky, 1995)

\textsuperscript{26} Available at \url{http://www.lean.org/WhatsLean/Principles.cfm} [Retrieved Sep. 4, 2011]
(b) There are interdependencies among elements in Table 3-12. For instance, ‘Built-in quality through the preparation, detection, correction, and prevention’ in the assembly phase includes almost all aspects of production control. ‘First-run study,’ ‘Make work flow predictable,’ and ‘Get feedback on effectiveness of production management’ in the same phase have similar production-control aspects. These interdependencies can cause the problem of multicollinearity if we use those elements as indicators for measurement of variables the way they are in Table 3-12.

In conclusion, current measurements of Lean Construction need to be calibrated so that they can be used as indicators for this research. Therefore, I decided to set my own systemized concepts/indicators for this research.

Table 3-12: Roadmap for implementing Lean projects (Ballard et al., 2007)

<table>
<thead>
<tr>
<th>Construction Phases</th>
<th>Activities for Roadmap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre project phases</td>
<td>Structure the project contractually and organizationally for pursuit of the Lean Ideal, using relational contracts, and cross-functional teams.</td>
</tr>
<tr>
<td>Project Definition Phase</td>
<td>Align ends, means and constraints.</td>
</tr>
<tr>
<td></td>
<td>Set targets for scope and cost based on aligned ends, means and constraints.</td>
</tr>
<tr>
<td></td>
<td>Set other targets for experimentation and learning.</td>
</tr>
<tr>
<td>Design Phase</td>
<td>Make work flow predictable through reliable promising and lean production control.</td>
</tr>
<tr>
<td></td>
<td>Follow set-based design strategy.</td>
</tr>
<tr>
<td></td>
<td>Design to target scope and cost.</td>
</tr>
<tr>
<td></td>
<td>Design product and process simultaneously; design for sustainability and constructability, including safe and defect-free fabrication and assembly.</td>
</tr>
<tr>
<td></td>
<td>Produce product specifications, fabrication instructions, installation instructions and system specifications from an integrated data base.</td>
</tr>
<tr>
<td>Supply Phase</td>
<td>Make work flow predictable through reliable promising and lean production control.</td>
</tr>
<tr>
<td></td>
<td>Prefabrication and preassembly.</td>
</tr>
<tr>
<td></td>
<td>Apply appropriate Lean tools and methods in fabrication shops; 5s, value stream mapping, points of use materials and tools, cellular manufacturing.</td>
</tr>
<tr>
<td></td>
<td>Fabricate at the last responsible moment to reduce the risk of design change.</td>
</tr>
<tr>
<td></td>
<td>Produce assembly packages by kitting fabricated materials with commodities not maintained in site stores.</td>
</tr>
<tr>
<td></td>
<td>Deliver assembly packages to site just-in-time.</td>
</tr>
<tr>
<td>Assembly phase</td>
<td>Implement the principle of providing materials and tools at the point of use through site stores and assembly packages.</td>
</tr>
<tr>
<td></td>
<td>Maintain commonly used and relatively small items (safety equipment, small tools, consumables, fastener, etc.) in site stores. Replenish using Kanban or vendor-managed inventory.</td>
</tr>
<tr>
<td></td>
<td>Do first-run studies to improve the safety, quality, time and cost of operations (placing concrete, pulling cable, setting equipment), involving craft workers in operation design, testing and improvement.</td>
</tr>
</tbody>
</table>
Achieve Built-in Quality through preparation, detection, correction and prevention.

Get feedback on the effectiveness of production management and suggestions for improvement from craft workers through surveys and interviews.

Apply other appropriate lean tools and methods in site assembly (e.g., layout for minimal travel time and 5S.).

Use commissioning and start-up to verify delivery to requirements.

Transfer information (model, as built, equipment manuals) to operators for use in operations and maintenance.

Conduct a post-occupancy evaluation to verify understanding of the purpose of design and construction.

Collect feedback from members of the project delivery team and other stakeholders on lessons learned.

<table>
<thead>
<tr>
<th>Use Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use commissioning and start-up to verify delivery to requirements.</td>
</tr>
<tr>
<td>Transfer information (model, as built, equipment manuals) to operators for use in operations and maintenance.</td>
</tr>
<tr>
<td>Conduct a post-occupancy evaluation to verify understanding of the purpose of design and construction.</td>
</tr>
<tr>
<td>Collect feedback from members of the project delivery team and other stakeholders on lessons learned.</td>
</tr>
</tbody>
</table>

### 3.2.2 Basic principles in measuring Lean Construction

It is hard to define ‘what the basic elements of Lean Construction are’ based only on some cases. Even though several, not many, projects showed good performance as a result of following some principles, we cannot say the principles caused the good results because there were not enough cases to be generalized. Thus, rather than extracting the basic principles from many cases, I decided to investigate specially designed simulations or role-playing games rooted in Lean Construction in order to set the principles first and to diversify those principles into measurable indicators through additional literature reviews.

Fortunately, a certain number of role-playing games have been developed to teach the effects of Lean principles. The Airplane Game, Parade Game, and Beer Game[^27] (http://beergame.mit.edu/guide.htm) explain the main principles of Lean Construction in very effective ways. Due to this effectiveness, they are being presented in graduate courses in which Lean Construction is taught, such as the UC Berkeley graduate program in Civil and Environmental Engineering. All the games show that following Lean principles could bring excellent results manifested by some metrics, such as reduction of lead time, reduction of inventories, and so on.

Briefly, the Airplane Game assigns individual tasks to five production units in order to make airplane LEGO blocks but it uses different principles to make the blocks at several rounds. The main purpose of airplane game is to compare the outputs among the different rounds. The first round employs none of the Lean principles that follow: 1) pull mechanism, which means working only when the next production unit requests; 2) distributed quality control; 3) minimized batch size; 4) pay based on team performance; and 5) optimized site working logistics. The second round employs only 5) optimized site working logistics among the aforementioned 5 principles. The third round employs 1) pull mechanism; 2) limited quality control, in which the individual production units correct their own faults while full quality control lets all participants be able to correct other workers’ faults; 3) minimized batch size; and 4) optimized site working logistics. The fourth round adopts all five aforementioned principles. An example of the

[^27]: Even though Beer Game illustrates how the lack of transparency in a supply chain results in over-reactions by its different players, if we apply Beer Game into big phases in a construction project such as feasibility study, design and construction that can be separated according to contractual structure, I think we can see similar results of unclear communication among the phases.
comparison shows a remarkable result in which the first round produces 5 blocks in 6 minutes; the second round produces 10-to-14 blocks in the same duration; the third round produces 20-to-25 blocks in the same duration; and the fourth round produces 35-to-40 blocks in the same duration. The principles of Lean Construction, shown in the Airplane Game, are summarized in Table 3-13. Ballard (2007) and Rybkowski et al. (2008) shows the result of Airplane Game by recording several role-playing games or computer simulations.

Table 3-13: Airplane Game’s principles (Ballard, 2007)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Distributed supervision (faults in upstream can be detected and cured by downstream workers) is better than centralized inspections.</td>
</tr>
<tr>
<td>2</td>
<td>Smaller batch size is better than bigger batch size.</td>
</tr>
<tr>
<td>3</td>
<td>Incentive based on team performance in payment is better than that based on individual achievement.</td>
</tr>
<tr>
<td>4</td>
<td>Pull system is better than push system.</td>
</tr>
<tr>
<td>5</td>
<td>Well organized site logistics</td>
</tr>
</tbody>
</table>

Similarly, the Parade Game varies production rates of individual trades delivering products (e.g., coins or bolts) as the stages are changed in order to compare the overall productivity of the parade of the trades among the different stages. For example, at the first stage, trade 1 can produce only 1 or 9 products alternately at a time; trade 2 can produce 2 or 8 products alternately at a time. The production rate can be determined by chance or by a deterministic rule. This game shows that the greatest throughput occurs when the production rates are evenly assigned among trades and when there is no variability in assigning the production rates to trades.

The Parade Game is represented by the simulation in Tommelein et al. (1999), which comprises five production units whose capacities are determined deterministically (reliable work flow without variability) or probabilistically (unreliable work flow filled with variability). This shows that unreliable work flow has to spend more labor with more inventories to produce the same amount of products.

The Beer Game is a role playing game describing beer (actually, small pennies in the game) delivered from beer factory to retailer. The players represent a retailer, a wholesaler, a distributor and a factory. The retailer orders beers from the wholesaler to meet the customer’s demand, the wholesaler orders beers from the distributor to meet the retailer’s demand, the distributor orders beers from the factory to meet the wholesaler’s demand. Each week, each player tries to meet the downstream players’ orders. Any order, which cannot be met, is a back order and should be met as soon as possible. It takes two weeks for an order to reach the upstream supplier and takes two weeks for the ordered beers to reach the downstream customer. Each week, each player is charged $1 per unit of backorder of beer and $0.5 per unit of inventory of beer. Players cannot communicate with each other directly. Information is delivered only through orders and shipments. Every player’s purpose is to minimize the total costs. Every simulation shows similar results. The amplitude of variance of orders steadily increases as the supply chain goes further upstream, away from the retail customer.

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29 http://www.ce.berkeley.edu/~tommelein/parade.htm
The Beer Game shows clearly that when is are no clear and timely/sufficiently communication between upstream and downstream suppliers in a supply chain, the inventory management cost and the backorder cost of each supplier becomes greater as we move upstream on the supply chain (Li et al., 2002). This symptom is called the Bullwhip effect. The logic of the Bullwhip effect is very simple: When there is a time gap between receiving orders and issuing the orders, each supplier should prepare its inventories for the next ordering based on estimation. But, the estimation is just an forecast of the future demands, and the probability for the estimation to predict real demands diminishes as the number of suppliers becomes bigger.31

The lessons of the Bullwhip effect are simple:

1. Transparent and timely communication among participants in a project will reduce waste and unnecessary costs
2. When limited communication is inevitable, then reducing the number of processes in a supply chain will reduce waste.

The Design–Bid–Build system is a good negative example of the first lesson of the Bullwhip effect. When the owner completes the design before bidding, there is no communication between the owner and the contractor who will perform the project after bidding. And also, when the contractor makes the bid price of the design, there is no transparent information exchange between the owner and the contractor. In addition, the competitive bidding based on the minimum bid price prevents the contractor from making a real estimated cost of the project reflecting the real working conditions because the purpose of the estimation is to make the least cost not the real cost, which means the lack of communication between the contractor and the actual construction site. The result of these miscommunications is an incomplete design fixed in a contract. The fact that Design–Bid–Build projects would undergo many change orders is not a strange feature in the recent construction industry, which reflects well the first lesson of the Bullwhip effect.

If the second lesson of the Bullwhip effect is right, the industry would have tried to reduce the distance between the real provider and the end customer in a supply chain. We can see the exact example showing this trend in the change of the London underground supply chain. The traditional form of the supply chain was governed by a professional body such as engineers, but the recent form shows a more direct link between the supplier, the operator and the customer (Tommelein et al., 2003).

All the principles (or lessons) discussed above can be categorized into two basic principles. The first is ‘incentives based on team performance’, and the second is ‘reducing variability.’ The first basic principle can be translated into ‘aligning goals toward the goal of a project’ because the role of incentive in a team is to integrate the capacities of all the individual participants to create better performance. The second principle is divided into two sub-principles, which will be discussed later. Parade Game and Beer Game explain reducing variability through process innovation for less waste and Airplane Game addresses aligning goals toward the goal of the target project.

31 If the probability is 0.8, then the probability of the 10th supplier from the end customer to hit the real demand is 0.8^10=0.107.
In addition to simulation of Airplane Games (Rybkowski et al., 2008), many real projects have shown that using incentives based on team performance is effective in achieving better performance, so that a number of techniques have been revolutionized to combine incentives and existing management techniques. Target Value Design (TVD) is one example of the most recent techniques developed in Lean Construction as a result of this enlightenment. TVD has nine foundational practices, all of which should be treated concurrently. The first practice is to establish target values with the client (Macomber et al., 2009). The target values (target cost/target duration) in TVD are the basis for incentives based on team performance, of which the difference from real project cost/duration achieved at the completion of the project would determine the allocations of pain/gain for each member. After setting incentives based on target values, TVD uses Set Based Design (SBD) strategy that is one of the representative design management practices in Lean Construction in order for the design to consider target values decomposed into project components as constraint.

The series of processes setting incentives in TVD is called Target Costing, which requires all relevant construction participants to participate in a feasibility study, to produce the expected values (cost/duration) of a project, to set target values (cost/duration) less than or equal to the expected values with pain/gain sharing principles based on the extent to which the real values (cost/duration) are under run or over run compared to the target values (Ballard, 2006). TVD or Target Costing gives this research more justification to adopt ‘aligning goals toward project’s objectives’ as one of basic principles of Lean Construction in that they are recently developed Lean Construction tools due to its advantages and they have proven the advantages in several projects, such as the CPMC Cathedral Hill Hospital Project (Ballard, 2010), or Sutter Medical Center Castro Valley (Tiwari, 2009).

The two basic principles, ‘aligning goals toward the project purpose’ and ‘reducing variability in project plans’ are described in Table 3-14.

Table 3-14: Basic principles of Lean Construction

|   | Aligning goals of all the participants toward project objectives
|   | Reducing variability in project plans
| 2-1 | Restructure the traditional processes to reduce non value adding time
|     | - Set-Based Design (elimination of negative iteration, see section 3.2.4)
|     | - Value Stream Analysis (reduce waste, see section 3.2.4)
| 2-2 | Reduce variability in the entire restructured process
|     | - Last Planner™ (production control based on plan reliability, see section 3.2.5)

32) 1) Engage deeply with client to establish target values, 2) Lead the design effort for learning and innovation, 3) Design to detailed estimate, 4) Collaboratively plan and re-plan the project, 5) Concurrently design the product and process in design set, 6) Design and detail in the sequence of the customer who will use it, 7) Work in small and diverse group, 8) Work in a big room, and 9) Conduct retrospectives throughout the process.

33) Looking from a longer term perspective, ‘continuous improvement’ is more appropriate as a basic principle, with variability reduction as a means to that end. However, for a single project, reducing variability makes sense as an indicator to improve performance.
3.2.3 Indicators of ‘Aligning goals toward project objectives’

Incentives cannot exist in a strict transactional contract. Customers want contractors to deliver the exact products as defined in pre-made designs of transactional contracts. Usually, customers recognize that the reduction of costs or durations is already realized in minimum-price bids used usually in a transactional contract’s procurement. Thus, they don’t need additional incentives, and the contractors also resist further reductions in costs or duration.

But, the design that was made long before the construction of a project might not reflect the real conditions at the time of construction and might probably cause change orders involving additional costs or time. Also, the courts came to recognize the tendency of design separated from real construction toward incompleteness of a project and found that a transactional contract is not appropriate in dealing with disputes in the current business (Beale, 1980). For the same reason, strict transactional contracts become what parties are reluctant to make (Campbell et al., 2005).

Recent practices seem to show that the reduction of cost and time made by competitive bidding is not appropriate. Instead, they suggest that an appropriate contract should have open-endedness to cope with potential uncertainties. Open-endedness is defined, loosely, as allowing a wide margin for renegotiation of commitments or even eschewing attempts to give those commitments any definite form at the outset but waiting for circumstances to arise which will allow such definition (Campbell et al., 2005). In order to draw that best performance, I believe, such open-endedness should be combined with appropriate incentives, rewarding the team of contractors according to the degree of performance.

Another problem with transactional contracts is that they tend to encourage local optimization. Under perfect transactional contractual circumstances, every participant in a project would try to optimize only its part restricted in each separate contract. But, this kind of sub-optimization harms the overall performance of a project because the performance of the project is a result of a lot of interdependent processes of each participant (Ballard, 2000b). Open-endedness and incentive based on team performance are necessary to prevent sub-optimization.

To achieve the open-endedness, at least the main contractor and key specialty contractors should participate in making the design. The incompleteness of the design at the time of procurement of the contractor is the basic part of the open-endedness. As the design becomes more specific through collaboration, the scope of the project, which has been left as open-ended, becomes clearer. In this collaboration, the information gap between participants and real construction conditions would be minimized, as well as the probability of change orders. In the same context, Saunders et al. (2005) regarded it as essential to harness the maximum input to design development and risk management from the main contractor (the ‘constructor’) and its specialist subcontractors at the earliest stage of a project in order to obtain the best value from the project.

To set incentives for a project, we need to establish the aforementioned target cost, based on which the amount of rewarding is determined in comparison with the resultant performance of the project. Before establishment of target values, Ballard (2006) suggested investigating the current best practices to produce a reliable expected cost (cost benchmark), one of the results of a project feasibility study. The expected cost of a project is for checking feasibility of project scope compared to the owner’s allowable cost/duration. But one unique feature of a project feasibility study in Lean Construction is that an expected cost is the previous step to establishing a target cost.
As we saw earlier, the purpose of target cost is to set incentives based on team performance so that both expected/allowable cost and target cost need collaborative input from every relevant participant. In short, the general contractor and specialty contractors who are supposed to deliver a project should participate in producing the expected cost of the project as well as the target cost with incentives if the project seeks the Lean Ideal (Ballard, 2006). The series of expected/allowable cost, target cost, and pain/gain sharing with collaboration can be the basis of the first principle in Table 3-14. Again, the expected cost of a project is used to produce the target cost of the project. Thus, the target cost of a project should be less than the expected cost, which should be less than the allowable cost.

The incentives would be decided based on the difference between the target cost and the actual cost at the time of project completion. If the actual cost is less than the target cost, the profits would be distributed among all the participants; but if not, the cost overrun would also be distributed. Sakal (2005) introduced a good example of this pain share/gain share mechanism, named the Limb 3 strategy (A.1). This strategy gives us an important insight comprising the first basic principle, as in the following quote:

*There should be formulas or principles about distributing the difference between the actual cost and the target cost when the parties make the contract of a principle.*

So far, what we overlooked is the selection process in light of the first basic principle in Table 3-14. In short, every owner needs to select trustworthy contractors. Even though a project has a well structured pain/gain sharing system, if the selected contractors tend to take advantage of customers’ lack of knowledge, they can easily exaggerate the expected cost/schedule when they are participating in the design. This type of mistrust is not uncommon in the construction industry. Winch (2000) asserted that entrepreneurs will seek self-interest at the expense of social welfare, unless there are regulations that make most governments depend on the designing of the professional group (architect, designer, and quantity surveyors) instead of having constructors make the design of a project.34

In addition, this mistrust of customers has forced contractors to focus more on preparation for potential litigation due to the incompleteness of designs than on the delivery of better products. In short, this mistrust has been the main cause of separation of design from construction and its side effects. If we do not take a design–bid–build strategy based on a minimum price bid, the next problem, induced from this mistrust, is how to select reliable contractors who would not take advantage of owners using the opportunity to shape design. In short, we should select only trustworthy contractors before entering the designing process.

In the same context, Allen et al. (2004) introduced the criteria based on trustworthiness used in an Australian national museum project (Table 3-15), but it has many abstract terms, which makes it hard to be taken as an indicator for this research. Thus, to make matters simpler, I assume that the trustworthiness of a contractor can be representatively measured by the average performance of past projects of the contractor. The more customers who have been satisfied with a contractor’s jobs there are, the bigger the trustworthiness of the contractor exists. But this is not so simple because, first, the performance considering overall aspects is really hard to measure, so that we hardly have an objective measurement tool of performance.

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34 After the United States Government took the largest role in building infrastructure after the 1930’s economic crisis, Design-Bid-Build appeared in most public projects, even though the combined and direct delivery method had governed infrastructure projects before the economic crisis (Miller, 2000).
Second, there may not be an information data base that stores the performance of past projects. Selecting trustworthy contractors might be possible theoretically, but this research roughly defines it as selection based on performance, considering not only minimum-bid prices.

Table 3-15: The Australian national museum project’s criteria to select contractor (Allen et al., 2004)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Demonstrate the ability to complete the full scope of works including construction, and structural/mechanical/landscaping design.</td>
</tr>
<tr>
<td>2</td>
<td>Demonstrate the ability to minimize project capital and operating costs without sacrificing cost.</td>
</tr>
<tr>
<td>3</td>
<td>Demonstrate the ability to achieve outstanding quality result.</td>
</tr>
<tr>
<td>4</td>
<td>Demonstrate the ability to provide the necessary resources for the project and meet the project program (including resumes of Key staff).</td>
</tr>
<tr>
<td>5</td>
<td>Demonstrate the ability to add value and bring innovation to the project.</td>
</tr>
<tr>
<td>6</td>
<td>Demonstrate the ability to achieve outstanding safety performance.</td>
</tr>
<tr>
<td>7</td>
<td>Demonstrate the ability to achieve outstanding work place relations.</td>
</tr>
<tr>
<td>8</td>
<td>Successful public relations and industry recognition.</td>
</tr>
<tr>
<td>9</td>
<td>Demonstrated practical experience and philosophical approach in the area of developing sustainability and environmental management.</td>
</tr>
<tr>
<td>10</td>
<td>Demonstrated understanding and affinity for operating as a member of alliance (collaborative experience and views on risk/reward schemes).</td>
</tr>
<tr>
<td>11</td>
<td>Substantial acceptance of the draft alliance document for the project including related codes of practice, proposals for support of local industry, and employment opportunities for Australian indigenous peoples.</td>
</tr>
<tr>
<td>12</td>
<td>Demonstrated commitment to exceed project objectives.</td>
</tr>
</tbody>
</table>

In summary, the first basic principle, ‘aligning goals toward project objectives’ is defined as a combination of the following indicators.

(a) Contractors and specialty contractors should participate in producing the expected cost (duration) of the project, based on the investigation of current best practices.

(b) A project should set the target cost (duration) less than or equal to the expected cost (duration) with the agreement of all the participants.

(c) There should be formulas or principles about distributing the difference between the actual cost (duration or other performance) and the target cost (duration or other performance) among participants in contracts.
3.2.4 Indicators of Value Stream Analysis and Set Based Design

The principle is ‘Restructure the traditional processes to reduce non value adding time.’ To implement this principle, the first job should be to analyze all the processes in terms of creating value to the end customer. The processes that do not create value or contain waiting time should be eliminated or reduced. This technique is called Value Stream Analysis (VSA).

To do the VSA, first, we should do Value Stream Mapping (VSM), which is to create a map of the flow of material and information from the customer back to each production process. Then, we should determine what value a product or a service has for the end customer. According to the amount of value or waste, we eliminate or restructure the processes, as defined in VSM (Arbulu et al., 2003).

The time we should start VSA intensively is at the start of the design, right after the feasibility study, which produces the design concept and the expected cost (duration) based on the current best practices. VSA should be used to imbed the target cost (duration) into the design. Usually, when we say ‘design,’ we call it ‘product design,’ but cost management should consider ‘process design’ (Nguyen et al., 2008). VSA is for a process design. Table 3-16 shows the main directions for VSA.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Minimizing batch sizes of materials in the map, which are transformed as they go through works</td>
<td>Arbulu et al., 2002</td>
</tr>
<tr>
<td>2 Changing the locations and sizes of storages between works in the map in order to meet demands of downstream processes</td>
<td>Walsh et al., 2004; Howell et al., 1993</td>
</tr>
<tr>
<td>3 Employing pre-assembly processes in the map to reduce installation time of items, such as pre-wiring of light, pre-mated plugs, using mounting system of a light attached directly to the ceiling modular grid, and so on</td>
<td>Tsao et al., 2001</td>
</tr>
<tr>
<td>4 Providing communication channels among works in the map, about who produces what, when, and where</td>
<td>Tommelein, 1998</td>
</tr>
<tr>
<td>5 Locating deliveries of items that have longer lead times at earlier stages of the supply chain in the map than other items</td>
<td>Walsh et al., 2004</td>
</tr>
<tr>
<td>7 Standardizing materials, processes, or facilities in the map</td>
<td>Tommelein, 2006; Tommelein, 1998</td>
</tr>
<tr>
<td>8 Combining or restructuring of the existing processes to reduce lead time</td>
<td>Howell et al., 1993</td>
</tr>
</tbody>
</table>

Table 3-16: Main directions for VSA

As we see in Table 3-16, the level of detail of the VSA ranges from the most to the least. A detail-level VSA should be done only after completing the appropriately matched detail product design. Process design and product design should be considered simultaneously in managing the total cost (Nguyen et al., 2008) because the variation of cost, depending on the process design, can influence the total cost of a project as well as that of the product design. Therefore, VSA, a guideline for a process design, should be done no later than the appropriate product design. The notion that the process design should be done earlier than the product design or done at the same time is represented in the Lean Project Delivery System (Ballard, 2006: Figure 3-5).
The innovation of current system is not restricted to VSA on process design. The method to produce product design, normally called ‘design’, should also be considered because there is a very important concept called ‘negative iteration’ producing unnecessary waste in time and labor. Ballard (2000-a) exemplified ‘negative iteration’ by showing a beam penetration case, in which every design specialist made its own decision without consulting downstream engineers’ opinion, with the result that all of them continued correcting upstream decisions whenever they reviewed the design.

In common sense, Value Engineering (VE) in a product design can be regarded as the counterpart of VSA because VE’s purpose is also to create more value from the existing design made by a customer. However, in view of Lean Construction, VE is not an appropriate strategy for a product design because it should undergo at least one unnecessary process, a negative iteration between the original design and the innovated design, which would not have existed if the contractor creating the VE design had been involved in the original design process in the beginning.

According to the Circular A-131 (the USA’s Office of Management and Budget, 1993), VE is ‘an organized effort directed at analyzing the functions of systems, equipment, facilities, services, and supplies for the purpose of achieving the essential functions at the lowest life-cycle cost consistent with required performance, reliability, quality, and safety.’ Only with this definition, it is not clear if VE needs a pre-made design.
However, we can see that, in real world, VE is for analyzing a pre-made design having been produced by the customer in the following definition of Value Engineering Change Proposal (VECP) in the Circular A-131, which is ‘A proposal submitted by a contractor under the VE provisions of the Federal Acquisition Regulations that, through a change in a project’s plans, designs, or specifications as defined in the contract, would lower the project’s life-cycle cost to the government.’

The designer who had made the previous design didn’t know anything about the works of those who did the VECP. Due to the lack of information, those doing VECP should review the previous design from the beginning to modify it. These reworks would increase as the number of reviewing points increase. That is the negative iteration performed through a point-based decision making (Ballard, 2000-a). Again, we can say VECP has at least two separate reviewing points in design. Instead of this point-based design strategy, Lean Construction adopts Set Based Design (SBD) strategy. SBD urges all the relevant participants to collaborate in producing every possible design alternative and to collaborate in analyzing if each alternative is feasible concurrently. The feasibility test should see if alternatives are within constraints, including the target cost (duration) having been decomposed into the relevant components of the project (Ballard, 2000-a). The inappropriate design alternatives that cannot pass the constraints should be deleted until the design team reaches the last responsible moment at which there is no longer sufficient lead time to realize other alternatives to the best fit design (Ballard, 2000-a).

Decomposing a target cost/schedule into components of the construction facilities (Ballard, 2000-a) is the link between Target Costing and SBD because the target cost/schedule has been established in Target Costing and is used as a strong constraint to narrow down design alternatives in SBD. The purpose of connecting target costing and the SBD is to design to target cost without negative iterations (Ballard, G. 2003). As we saw earlier, Target Costing belongs to the first basic principle in Table 3-14, while SBD is part of the second principle. I decided that decomposing a target cost/schedule should be considered as an indicator of SBD comprising the second basic principle in Table 3-14.

In summary, the first part of the second basic principle, ‘Restructure traditional processes to reduce non-value-adding time’ needs the following indicators.

(a) Target cost (duration) should be decomposed into each component of a project while making the product design and the process design through the consensus of all relevant participants.

(b) All relevant project participants should produce as many design alternatives as possible during product designing.

(c) Inappropriate design alternatives should be eliminated as investigations and removals of constraints go on, until they reach only the best alternative (SBD).

(d) Every representative member who is responsible for a component of a project should participate in making alternative designs related to the component (SBD).

(e) Every representative member who is responsible for a component should participate in making a process design for the component, considering the alternatives of designs related to the component (Integrating a product design and a process design).
(f) The process design corresponding to each alternative design should be made in a way that the following principles are met, if possible (VSA):

(f-1) All possible works and materials should be standardized.

(f-2) The batch of material delivered between processes should be minimized.

(f-3) The inventories of materials between processes should be located in such a way that minimizes the waiting time of each material stored in the inventories.

(f-4) The materials to be installed should be preassembled if it would shorten the installation duration.

(f-5) Deliveries of the materials that take more time to deliver should be started earlier than other materials

3.2.5 Indicators of production control (Last Planner™)

The target principle in Table 3-14 is “Reducing Variability in all the restructured process.” This research defines the variability as deviance from the planned. While the first part of the second basic principle is about innovation of design, plan or process, themselves, this part is to execute the plans having been innovated by the SBD or the VSA.

If a project is supposed to be measured by its variability, it implies all the possible works should be planned before being measured. Therefore, Lean Construction recommends that every activity should be planned in detail before being initiated. But, designing of processes at a very detailed level is not a unique feature of Lean Construction. For example, Ibbs (2007), in his graduate class on general construction management, suggested a list of works to be done in project planning, as shown in Table 3-17. This table shows nearly every aspect of a work is recommended to be designed.

<table>
<thead>
<tr>
<th></th>
<th>What should be determined in project planning (Ibbs, 2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scopes of works</td>
</tr>
<tr>
<td>2</td>
<td>Constraints and milestones of works</td>
</tr>
<tr>
<td>3</td>
<td>Methods and resources in order to execute works</td>
</tr>
<tr>
<td>4</td>
<td>Estimation of durations and amount of resources for works</td>
</tr>
<tr>
<td>5</td>
<td>Establishment of dependencies and logics among works</td>
</tr>
<tr>
<td>6</td>
<td>Calculations of critical paths, starting and finishing times, and floats of works</td>
</tr>
</tbody>
</table>

Compared to general project planning, what makes planning of Lean Construction unique is the timing of the planning. Lean Construction’s variability is measured against weekly work plans rather than nominal schedules (e.g., master schedule, or phase schedule) because Lean Construction believes it is reasonable to plan a work in detail only after all possible constraints are defined and removed.
Last Planner™ (LP), one of the representative production-control systems in Lean Construction, regards reducing variability in executing project plans as the primary goal. As for the effectiveness of reducing plan variability, Liu et al. (2008) suggested a regression line\(^{35}\) between plan reliability and productivity and Alarcon et al. (1997) showed the graphical difference of productivity before and after implementing LP.

Those research projects have shown that reducing plan variability increased construction productivity directly, and LP has been created to maximize reliability of work/material/and information flow to minimize waste in time/money in project processes and to maximize customer value (Ballard, 2000). Thus, in order to make indicators representing Lean Construction about the reduction of project plan variability, we need to investigate LP. LP is known to have four main processes: 1) master schedule; 2) phase schedule; 3) look-ahead plan; and 4) weekly work plan (Hamzeh, 2009).

A master schedule, the biggest schedule, defines important milestones, such as the start and end dates of the construction phase. Usually, this reflects the owners’ or the main stake holders’ important milestones. The second biggest schedule is the phase schedule, which specifies all the handoffs in a phase in terms of sequences and durations considering contingency of each handoff. Table 3-18 shows examples of handoffs in a Phase (Ballard et al., 2003). Because the handoffs of a Phase in Lean Construction are very detailed, all workers in a phase need to collaborate to make an appropriate schedule of the phase.

<table>
<thead>
<tr>
<th>Phase</th>
<th>(Within an ‘Office Building’ construction) Site preparation, Substructure, Superstructure, Skin, Building system, and Fit out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>(Within a ‘Substructure’ phase) Layout, Excavate, Shore, Place drilled caissons</td>
</tr>
<tr>
<td>Operation</td>
<td>(Within a ‘Place drilled caissons’ process) Fabricating cage, drilling hole, placing cage, pouring concrete</td>
</tr>
<tr>
<td>Step</td>
<td>(Within a ‘fabricating cage’ operation) Acquire materials, place straight bar in jig, weld coiled bar helically around cylinder, fit &amp; tack lifting bands, weld out lifting bands</td>
</tr>
</tbody>
</table>

A look-ahead process of a work planned in a phase schedule, the third biggest schedule, is designed to remove all constraints of the work during a look-ahead period, around six weeks before the execution of the work. Examples of constraints are listed in Table 3-19. In common sense, ideal constraint analysis of a work should be done by the constructor of the work. Thus, a look-ahead process in Lean Construction also requires every worker to analyze and remove his/her constraints.

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\(^{35}\) Labour Productivity = 0.530 + 1.095*Weekly Plan Percent Completion
Table 3-19: List of constraints (Choo et al., 1999; Hamzeh et al., 2009)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Approvals defined in contract</td>
</tr>
<tr>
<td>2</td>
<td>Timing of submittals, shop drawings, or request for information</td>
</tr>
<tr>
<td>3</td>
<td>Material requirement about fabrication, supply, and requests for quotation</td>
</tr>
<tr>
<td>4</td>
<td>Required labor and equipment</td>
</tr>
<tr>
<td>5</td>
<td>Prerequisite work</td>
</tr>
<tr>
<td>6</td>
<td>Site conditions</td>
</tr>
<tr>
<td>7</td>
<td>Funds</td>
</tr>
<tr>
<td>8</td>
<td>Climate</td>
</tr>
<tr>
<td>9</td>
<td>Experimental study to see if there are other constraints which are omitted in anticipation (a first run study)</td>
</tr>
</tbody>
</table>

A weekly work plan finally investigates the appropriateness and readiness to be executed of a work with quality criteria right before it is executed (approximately a week before execution). The quality criteria are listed in Table 3-20.

Table 3-20: Quality criteria in a weekly work plan (Tommelein et al., 1997)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Whether or not the work has a concrete definition.</td>
</tr>
<tr>
<td>2</td>
<td>Whether or not the work is ready to be executed by completing design and pre-requisite work.</td>
</tr>
<tr>
<td>3</td>
<td>Whether or not the work has appropriate size fitting the capability of the workers.</td>
</tr>
<tr>
<td>4</td>
<td>Whether or not the work has the right sequence with the previous and subsequent works.</td>
</tr>
<tr>
<td>5</td>
<td>Whether or not the work applies the correction of reason, which caused failures in the past.</td>
</tr>
</tbody>
</table>

Again, the variability of a work in LP is measured by investigating whether or not the weekly work plan is done successfully. Thus, the variability is represented by the Percentage of Planned work Completed (PPC) per week (Ballard, 2000-b). However, I decided to include checking quality criteria before one week into the indicators to measure the look-ahead process, instead of making separate indicators to measure how to apply quality criteria in the weekly work plan, because checking quality criteria of a work one week before execution is definitely a part of constraint analysis. But some unique indicators such as learning from failures of a weekly work plan, checking PPC, or modification\(^{36}\) of decisions made before a weekly plan caused by inappropriate constraint analysis are left as separate indicators.

The next thing is to realize the distributed control. In general project management, high-level schedules push subordinate schedules regardless of real condition, which often cause delay. One of LP’s purposes is to eliminate all constraints before doing a work in order to maximize plan reliability. Thus, under this condition, a predetermined schedule might be able to be adjusted based on constraint analysis as time gets nearer to the execution. In addition, because idealized constraint analysis of a work could be done by the right executor of the work, every worker

\(^{36}\) This is one of the distributed controls of LP, which is discussed immediately after this sentence
should be able to modify the relevant schedules if he/she finds a wrong decision was made in other relevant schedules that might interfere with the executions of his/her work during the constraint analysis. This is the core notion of distributed control. Systematically, this can be done by making a lower level’s planning be able to modify the right immediate higher level’s planning when there are problems made in the higher planning. The workers belonging to a phase should be able to request problematic decisions made in the master schedule to be modified when they find problems caused by the decision in making the phase scheduling. And that request should be solved by discussions with the relevant participants. In the same way, a look-ahead processing can modify those in the phase schedule; and a weekly work plan can modify those in the look-ahead processing.

The remaining task is to realize a pull system through a project. A pull system needs communication channels between adjacent production units and a rule that each production unit should produce handoffs delivered to the next production units only when the next unit demands the handoffs (Tommelein, 1998). Therefore, each production unit should communicate with the adjacent ones and investigate if the next production unit is ready to receive handoffs before producing the handoffs. Not only investigating the readiness of the next worker but also instant releasing of handoffs when possible is required to realize the pull condition.

In summary, the principle, “Reduce Variability in all the restructure processes” needs the following indicators:

(a) All handoffs and works in a phase should be defined in terms of sequence, duration, constraint, prerequisite works and contingency before entering the phase.

(a-1) Each relevant worker should be able to participate in defining his/her works.

(a-2) The degree of detail becomes finer as the execution of works is nearer.\(^{37}\)

(b) If a serious problematic decision that was made in the master schedule was found when the relevant workers are scheduling a phase, the decision should be modified through conversations with all relevant participants.

(c) The representative specialist for a work should be able to investigate and remove all the constraints (time, money, sequence, resources, prerequisite works, contractual approvals, and natural circumstances) of the work around six weeks before executing the work (The look-ahead process).

(c-1) The specialist could do an experiment with real resources to investigate if there is no constraint in executing a work (first-run study).

(d) If a serious problematic decision that was made in a phase scheduling is found regarding a work when relevant workers are doing look-ahead process of the work, the decision should be modified through conversations with all the relevant participants.

(d-1) Every worker always should compare what was done in the past and what should be done now in scheduling.

---

\(^{37}\) This is difficult to measure through a survey instrument, which is the main research methodology of this thesis. Thus, I decided not to include this in the survey.
(e) If a serious problematic decision that was made in a look-ahead process regarding a work when relevant workers are making a weekly plan of the work, the decision should be modified through conversations with all relevant participants.

(f) Every worker should investigate if the next production unit is ready to accept its handoffs right before releasing the handoffs based on the 'pull' signal

(f-1) There should be communication channels so that instantaneous information sharing is possible.

(f-2) Every worker does his/her job only upon request.

(g) All workers should investigate if the causes of failures in the past weekly work plans are removed before they execute the similar works.

(g-1) Every worker should be able to correct the causes of past failures if the failures are related to his/her works.

All concepts and indicators discussed so far are represented in Figure 3-6. The arrow is from an indicator to a basic principle as defined in Table 3-14; the dotted arrow is from a sub indicator to an indicator. All arrows are made based on literature review and those might be adjusted in real measurement, the detailed contents of which are discussed in Chapter 4 Research Methodology.
Figure 3-6: Concepts and indicators of Lean Construction
3.3 Defining Project Performance

Project performance is the dependent variable of this research hypothesis. Instead of considering overall performance, including value creation or benchmarked waste reduction that Lean Construction academic parts urge we consider in measuring project performance, this research mainly deals with the Commonly Acknowledged Performance (CAP), which is the minimal requirement to satisfy the customer, in defining the dependent variable because measuring overall performance is too difficult if the measurement extends to many research cases. The concept of CAP is also introduced in Cho et al. (2010). Cho’s CAP simply includes the cost reduction ratio compared to a budget approved by the owner, the schedule reduction ratio compared to a schedule approved by the owner, number of accidents per paid man-hour, and so on. We cannot say a project is good merely because its CAP is better than others. However, if a project does not show good appearance in CAP, definitely, it is not a good project because no owner will say it is satisfactory if its cost is overrun or if it is delayed compared to the promises among project parties.

There have been many trials to define performance indicators. CII (2003) defines cost performance (growth/reduction, conformance to phase plans, etc), schedule performance, Lost Work Day Case Incidence Rate, and Recordable Incidents Rate as performance indicators. The UK’s Rethinking Construction set reduction of construction cost/time/accidents and an increase of profitability/productivity/predictability/turnover & profits as targets for improvement (CTF, 1998). The Danish benchmarking system defined duration performance, change of cost and unit price, accident frequency, and defects during construction and after handing over, as key performance indicators (Cheung et al., 2004). Similar indicators have been developed by private researchers such as Cheung et al. (2004) and Chan et al. (2004). Based on those existing performance indicators, I defined performance indicators for this research as Table 3-21 shows. The performance indicators in Table 3-21 were to be measured in the survey of the first phase, discussed in section 5.2. However, some of them were found to be useless because of insufficient data so that I used only the sum of the ‘project cost-reduction ratio’ and ‘project schedule-reduction ratio’ in Table 3-21 since the survey in the second phase discussed in section 5.3.

Table 3-21: Project performance indicators for this research

<table>
<thead>
<tr>
<th>Objective factor</th>
<th>Total square meters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total paid man-hours</td>
</tr>
<tr>
<td>Cost</td>
<td>Project cost-reduction ratio = (approved budget- actual cost )/(approved budget or actual cost)</td>
</tr>
<tr>
<td>Schedule</td>
<td>Project schedule-reduction ratio = (approved schedule – actual schedule)/ (approved schedule or actual schedule)</td>
</tr>
<tr>
<td>Safety</td>
<td>The number of reported accidents, which caused human injuries</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>- Overall quality/functionality</td>
</tr>
<tr>
<td>(for interview if possible)</td>
<td>- Collaborative attitudes</td>
</tr>
<tr>
<td></td>
<td>- Conformance to reasonable requests</td>
</tr>
<tr>
<td></td>
<td>- Non owner participants’ satisfaction</td>
</tr>
</tbody>
</table>

For more information, see Table 3-22 representing the comparison among aforementioned performance indicators defined by Cheung et al. (2004), Danish Benchmarking system, Chan et
al. (2004), and Construction Industry Institute Benchmarking system. All of them commonly used cost performance, schedule performance, and safety performance as I defined for this research in Table 3-21.

Table 3-22: Comparison among the current Key Performance Indicators (KPI)

<table>
<thead>
<tr>
<th>Time</th>
<th>PPMS</th>
<th>Danish KPI</th>
<th>KPI of Albert, Chan</th>
<th>CII Benchmarking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1. Actual construction time including remediation of defects (defects liability period) vs. planned construction time (including alterations): 4 factors: 1) Date of start up of construction phase; 2) Planned handing over date; 3) Date of completed defects liability period; and 4) Alterations agreed with the clients or caused by external factor.</td>
<td>1. Construction time: Practical completion date – Project commencement date. <strong>2. Speed of construction:</strong> Gross floor area(m²) / Construction time (days/weeks). <strong>3. Time variation:</strong> the percentage of increased or decreased time compared to the total project period (original period + discounted effect of extension of time granted by owner).</td>
<td>1. Project schedule growth = (Actual total project duration – Initial predicted project duration)/Initial predicted project Duration. <strong>2. Project schedule factor</strong> = Actual total project duration/(Initial predicted project duration + Approved changes).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. Variation amount vs. original contract sum. 2. Certified amount of cost claims.</td>
<td>1. Changes of project price during the construction phase. 2. Square meter price.</td>
<td>1. Unit cost: Final contract sum/Gross floor area (M²). 2. <strong>Percentage of net variation</strong>=(final contract sum-original contract sum-final rise and fall + contingency allowances)/final contract sum*100 3. <strong>Net present value of the project.</strong></td>
</tr>
<tr>
<td>Safety accident</td>
<td>1. Number of accidents reported.</td>
<td>2. Number of man-days lost.</td>
<td>1. Accident frequency: a sudden, unforeseen and injurious work – related event causing bodily injury, frequency is the number of accidents per one million man hour.</td>
<td>1. Safety accidents’ rate: Total number of reportable construction site accidents/total number of workers employed on the project or man-hours worked on a specific project*1000.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Defects</td>
<td>1. Number of non compliance records received.</td>
<td>2. Number of non compliance records closed.</td>
<td>1. Number of defects entered in the handing over protocol, classified according to the degree of severity (4 categories): the number of defects is counted according to the number of defective construction parts.</td>
<td>2. Remediation of defects during the first year after handing over: it includes various extra works or additional services as long as those have not been agreed with.</td>
</tr>
</tbody>
</table>

**4. Phase cost growth**

\[
growth = \frac{\text{Actual phase cost} - \text{Initial predicted phase cost}}{\text{Initial predicted phase cost}}
\]

**1. Recordable incidence rate**

\[
\text{rate} = \frac{\text{Total number of reportable accidents}}{\text{Total number of workers employed on the project or man-hours worked on a specific project}} \times 1000
\]

**2. Lost workday case incidence rate**

\[
\text{rate} = \frac{\text{Total number of lost workday cases}}{\text{Total site work hours}} \times 200,000
\]

**1. Product quality achieved as planned.**

**2. Building functionality as planned.**

**3. Project quality as planned.**
| **Satisfaction** | 1. Quality of finished product.  
2. Ability to identify and resolve problem.  
3. Leadership skill.  
4. Speed and reliability of service.  
5. Ability to keep promise.  
6. Resolution of defects.  
2. Meeting schedule expectation.  
3. Meeting safety expectation.  
5. Meeting quality goals.  
6. Project team works/Project team communication.  
7. Working relationships among team members. |
CHAPTER 4: RESEARCH METHODOLOGY

4.1 Limits in view of internal validity

Causal inference between two variables needs covariance between the two without spuriousness, timely order (independent variable should precedes dependent variable), and theoretical mechanism (Bernard, 2000). The theory of Lean Construction can explain the theoretical mechanism but the problem is spuriousness because checking spuriousness comes from a strong internal validity in which all the independent variables are monitored and, sometimes, controlled like in a lab experiment.

Threats to internal validity place limitations on this research. An experimental research design that has strong internal validity requires random assignment of cases to different independent variables and observation of the variation among their dependent variables (Bernard, 2000). In the real world, this research cannot follow that kind of experimental design because we cannot make any contractual decision of any project of which we are not the owner. Only post-observation about the consequences of projects is possible. So, this research design takes a non-experimental design, with only post-observation (Trochim, 2006-a). In this case, there could be a lot of threats to internal validity, such as the selection bias caused by self-selection, maturation bias caused by the aging of cases, historical bias caused by outside historical events, instrumentation bias caused by an experimenter’s or subject’s mastery to the instruments (Hoyle et al., 2002).

Within non-experimental designs, there is the meta-analysis, but meta-analysis is not appropriate for this research. Meta-analysis is a systematic literature review (Hoyle et al., 2002) and is increasingly being compiled by those who advocate evidence-based remedies needing results from randomized controlled trials (Rybowski et al., 2008). However, the studies done on Lean Construction usually did not use randomized controlled trials. Instead, most of them used small N case studies, which lack statistical results such as Pearson’s R or Cohen’s D being important factors used in meta-analyses (Hoyle, 2002). In fact, randomized controlled trials are not possible in construction projects because variables cannot be fully controlled. Thus, the lack of randomized controlled trials in the relevant studies about Lean Construction means inappropriateness of using the meta-analysis in this research.
4.2 Combining quantitative and qualitative approaches

A quantitative approach adopts cause-and-effect thinking, hypothesis testing, and considering validity in measurements in developing knowledge, and uses experiments or surveys for statistical analysis, while a qualitative approach seeks multiple meanings of individual experiences, meanings socially and historically constructed with the intent of developing a theory or pattern, not a thing like hypothesis testing, and uses narratives, phenomenology, ethnography, grounded theory studies, or case studies. The mixed method is the one combining the previous two approaches on pragmatic grounds (Creswell, 2003).

This research strategy takes on the combination of Large N Analysis (LNA: Quantitative or Hypothesis testing) and Small N Analysis (SNA: Qualitative or Case study). Even though the existence of a research hypothesis implies that my research is likely to be a quantitative research, one should also consider the instances where the causal inference to be drawn from the hypothesis testing analysis is not clear. In such cases, there may be a need for modifying the hypothesis or the measurement used in the hypothesis test based on the consequences observed in the quantitative approach. This attitude takes on a mixed-research approach based on the results of the first quantitative methodology using a qualitative research that seeks how causes interact in the context of a particular case or in a few cases to produce an outcome (Andrew et al., 2006).

This research used SNA after a preliminary LNA. The principle is as follows: if the result of the LNA is satisfactory, the SNA is used for testing the regression model (Model Testing Small N Analysis in Figure 4-1) suggested by the LNA; but if the result is not robust to support the model, a SNA is used to build a new regression model (Model Building Small N Analysis in Figure 4-1). The next stages are assessments of the SNAs. According to the assessments, the direction of further analysis is determined. The detail is described in Figure 4-1 (Lieberman, 2005).
The next concern is how to select cases for the SNA. There are traditional strategies to select cases based on dependent variables of the preliminary LNA. The detailed strategies are as follows:

(a) Most Similar/Different Outcome (MSDO) strategy compares cases whose independent variables are similar but dependent variables are different.

(b) Most Dissimilar/Same Outcome (MDSO) strategy compares cases whose independent variables are different but dependent variables are similar.

(c) Most Similar/Same Outcome (MSSO) strategy selects cases by similar outcome and searches for similarities in prior conditions. (Lieberman, 2005)

These strategies (MSDO, MDSO, and MSSO) are explained visually in Figure 4-2 combined with Table 4-1.
Table 4-1: Case selection description (Lieberman, 2005)

<table>
<thead>
<tr>
<th>Kinds of analysis</th>
<th>Selection criteria</th>
<th>Figure 4-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNA for model testing</td>
<td>Predicted well by the best fitting statistical model (MSSO).</td>
<td>B, D, E, and F</td>
</tr>
<tr>
<td>The 1st SNA for model building or modifying</td>
<td>Deviant from the best fitting model by more than 2 standard deviations.</td>
<td>H</td>
</tr>
<tr>
<td>The 2nd SNA for model building or modifying</td>
<td>Similar and dissimilar outcomes in similar independent variables (MSDO).</td>
<td>A, D, and C</td>
</tr>
<tr>
<td>The 3rd SNA for model building or modifying</td>
<td>Similar and dissimilar independent variables in similar outcomes (MDSO).</td>
<td>B and G</td>
</tr>
</tbody>
</table>

But, mainly, this research focused on MSDO (case A, D, G, and H in Figure 4-2) and MSSO (case B, D, E, and F) in doing case studies. The purpose of MSDO is to find implicit independent variables that this research might have missed while setting measurement for the preliminary LNA. The implicit independent variables could give us an insight to develop the frame of Lean Construction which has been designed to enhance project performance, because such cases could tell us that Lean Construction probably missed those implicit but important factors at the beginning.

The purpose of MSSO is to support more the hypothesis test result by investigating if real works
within cases follow the track that the theoretical model, having established the measurement, predicts. For example, if a project records a higher score in Set Based Design (SBD) and if it gets a higher score in overall performance, a case study for model testing can reveal that negative iterations happened with less frequency because SBD is designed to enhance project performance by reducing negative iterations. This kind of case study is Process Tracing in Table 4-2.

As for MDSO case, this research did not take case studies to find out why the regression model cannot explain MDSO’s appearance. MDSOs show that there are unnecessary independent variables in the research measurement because big different values in independent variables result in the same or very similar values of dependent variables, or that there can be a problem in scoring variables. In that case, statistical analysis would find out unnecessary independent variables or defects in scoring variables instead of case studies.

The next concern is how to do case studies in SNA. Case study can contain nominal or ordinal variables, depending on what should be measured in each case. According to the nature of variables, the case studies can be the ones introduced in Table 4-2 (Mahoney, 2000). Usually, in MSDO, whose nature is comparison between different patterns’ cases, comparative analysis such as Nominal or Ordinal in Table 4-2 could be used while MSSO tends to take Process Tracing. Pattern Matching or Causal Narrative is not appropriate for this research. In my opinion, those can be used in research in which cases have similar sub-organizations in them, such as nations.

Table 4-2: Strategies for case study (Mahoney, 2000)

<table>
<thead>
<tr>
<th>Nominal</th>
<th>Comparative analysis between cases in measuring nominal (categorical) variables, which are mutually exclusive and collectively exhaustive.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordinal</td>
<td>Comparative analysis between cases in measuring ordinal (rank ordering) variables at high level of aggregation.</td>
</tr>
<tr>
<td>Within Case study</td>
<td>Pattern Matching</td>
</tr>
<tr>
<td>Process Tracing</td>
<td>To trace variables in order to find out causal mechanism between exploratory variables and outcome variables within a case.</td>
</tr>
<tr>
<td>Causal Narrative</td>
<td>To separate variables into constituent sequences of disaggregated events and comparing these disaggregated sequences across cases in order to determine whether cases can reasonably be seen as the following aggregated causal patterns at a finer–grained level.</td>
</tr>
</tbody>
</table>

More specifically, Process Tracing in this research was performed by asking additional questions, based on the theoretical principles of Lean Construction, through separate interviews. For example, as for Last Planner™ that reduces plan variability by removing all constraints before executing a work and by executing a work instantly when the next production units are ready, I asked the following additional questions, which have different forms from the previous survey
questions but which ask about the same concepts previously investigated by the survey instrument. Those following interview questions investigated if the intermediate processes in an individual case produced the expected outcomes from theoretically devised causal activities, such as Last Planner™ (LP) implementation.

<Preliminary explanation>

The production control of Lean Construction is comprised of three components. The first is to include a task on a weekly work plan only when all constraints are removed; the second is to release the work to the next worker only when the next production unit is ready to receive it; and the third is to release the work as soon as possible if the next production units are ready, so that there is no waiting time for the handoffs.

<Interview questions>

(a) Do you think those aforementioned principles will enhance the productivity or project performance?

(b) Do you think this principle was used in your project?

(c) If you assume the perfect condition for applying those aforementioned principles is 100, what score do you want to give to your project?

Another example is Set Based Design (SBD). The survey observes how a project team designed the product design in order to diagnose the degree of SBD implementation. However, an interview for Process Tracing of SBD asked if the respondent experienced less waste, or unnecessary iterations because of his/her SBD implementation, based on the theory that SBD is supposed to reduce negative iterations through collaborative review and constraint analysis in designing. The following questions were used in the interviews.

<Preliminary confirmation>

According to your responses, your designers always or often consult other designers, general contractor, and specialty contractor in order to produce as many design alternatives as possible while designing their parts. And you narrowed down these design alternatives as your constraint analysis progressed until you found the best design.

<Question>

(a) Do you think this SBD was really helpful to reduce reworks in the design process?

(b) If you set 100 as the perfect condition of collaborative reviewing and narrowing down of design alternatives, what score do you want to give to this project?

(c) What is the average score of the past projects in which you have participated?

Those aforementioned questions about LP and SBD are to be used for model testing studies, which ask if the cases located on or very near the regression line produced by the survey shows that the internal processes follow well the theoretical frame of LP and SBD. If the Lean Construction theory is correct in predicting project performance, the internal processes investigated by Process Tracing should show predictable appearances according to the theory.
Model building can use various questions that are not restricted to a certain type of theory, based on the survey responses, in order to find out what happened in the real project when the survey responses were not easy to understand. For example, if someone agreed that they had used all SBD tools and if they agreed that most of their design specialists started their participation only after their previous specialists had finished their works (Point-based design), then the respondent’s answers contradict each other. In that case, the interview for model building can explore the discrepancy and determine the actual facts of the case.

4.3 Conceptualization and operationalization

Again, the independent variable of the research hypothesis is the degree to which Lean Construction is implemented (in a project) and the dependent variable is the performance (of the project). The next thing to be considered is how to measure and score the variables. The variable is represented as a concept in the following Figure 4-3, which Adcock et al. (2001) made to explain conceptualization and measurement.

According to Figure 4-3, this research set ‘the extent to which a project implements Lean Construction’ as the background concept of the independent variable. Due to the broad and abstract feature of the background concept, we need more concrete and finer systemized concepts explaining the background concept, and indicators that are detailed components of systemized concepts in order to score cases.
The formation of systemized concepts needs good theory, and formulating good theory needs proper concepts (Adcock et al., 2001, and Kaplan, 1964). The literature review on Lean Construction in Chapter 3 is a journey to find theories comprising Lean Construction and to structure appropriate concepts making Lean Construction measurable. As a result of the journey, we can define sets of systemized concepts and indicators of independent variable of the research hypothesis, as Figure 3-4 shows.

The Operational definition is the specification of measurement of a variable in order to assign a score to the variable. The measurement can be a survey, a face-to-face interview, or internet polling (Hoyle et al., 2002). To measure systemized concepts and indicators in the LNA, a survey is taken because of its lowest cost and time efficiency. But the lowest response rate can be a main culprit harming the performance of a survey. For example, even though Sanvido et al. (1999) gathered data from 378 projects in order to compare advantages/disadvantages of three main types of project-delivery systems (Design-Bid-Build, Design-Build, and Construction Management at Risk), those were only 5.1% of the total population (7,600 projects). To increase the response rate, this research employed an online survey using e-mail instead of a paper survey mailed to respondents.

A face-to-face interview, phone interview, or visiting and observing a construction site would be appropriate forms of measurement for the SNA due to their excellent ability to clarify and probe, compared to a survey (Rick H. Hoyle et al., 2002). Sending additional e-mails is a good measurement to clarify something that the survey could not do. This research used additional e-mailing and phone interviews as tools of SNA.

Based on indicators so far, I made the initial survey instrument (A.2) to measure the independent variable and the dependent variable of the research hypothesis. This initial form was modified several times as the research went on according to the mixed research strategy, including the quantitative and qualitative approaches that were addressed in Figure 4-1.

Most of the questions in the survey instrument request answers in the form of frequency, percentage, and Yes/No, each of which has unique scores described in Table 4.3. Other questions asking answer types beyond Table 4.3 were measured with subjective criteria. The survey part measuring the degree of Lean Construction’s implementation is designed to produce a score as the representation of the degree by simply summing up all the answers’ scores. One thing I want to say here is that I did not take zero as a score intentionally, even if a respondent said ‘Never,’ ‘None,’ or ‘No,’ because I assumed that there should be some implementation of the principles measured to a degree in any project in that every contractor pursues the customer’s satisfaction.
Table 4-3: Scoring according to type of answer

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Score</th>
<th>Percentage</th>
<th>Score</th>
<th>Yes/No</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Always</td>
<td>1</td>
<td>All</td>
<td>1</td>
<td>Yes</td>
<td>1</td>
</tr>
<tr>
<td>Often</td>
<td>4/5</td>
<td>75% to 100%</td>
<td>5/6</td>
<td>No</td>
<td>0.25</td>
</tr>
<tr>
<td>Sometimes</td>
<td>3/5</td>
<td>50% to 75%</td>
<td>4/6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rarely</td>
<td>2/5</td>
<td>25% to 50%</td>
<td>3/6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>1/5</td>
<td>0% to 25%</td>
<td>2/6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

None 1/6

For understanding how to score survey, Figure 4-4 and 4-5 show the scoring structure of the survey for a Design-Build project. These pictures are restructured from Figure 3-4. Figure 4-5, the survey for the general contractor of a Design-Build project produces a total score of implementation of Lean Construction by adding up the score of the answers to each question, each box in Figure 4-5. The direction of an arrow is the direction of summation of the score. A green arrow comes from an indicator and goes to a systemized concept. A red arrow comes from a subordinate indicator and goes to an indicator. However, Figure 4-4, a survey for the owner of a Design-Build project does not produce scoring of project performance by just adding up the answer to each survey question. Every answer in Figure 4-4 is input to calculate project performance.
Design Build (Owner)

Facts for scoring performance

- Kinds of project delivery system (DB, IPD, Project alliance, Early involvement of Contractor, Indefinite Quantity)
- Completion year for timely longitudinal analysis
- Actual cost compared to planned cost in construction
- Actual time compared to planned time in construction
- Actual cost compared to planned cost in product design
- Actual time compared to planned time in product design
- Square footage of the facility constructed by a project
- Paid man hour to repair the defects after turn over
- Total paid man hours for construction
- Time used in procuring contractors and architect
- The number of safety accidents
- Subjective quality: overall functionality, responses to the appropriate requests, and collaborative process
- Raking of past performance in selecting architects
- Raking of past performance in selecting contractors
- Aligning Goals
  - Raking of past performance in selecting architects
  - Depth of measuring past performance in selecting contractors
  - Depth of measuring past performance in selecting architect

Figure 4-4. Scoring structure of the survey for a Design-Build project’s owner
Figure 4-5. Scoring structure of the survey for a Design-Build project’s contractor
4.4 Validity and reliability of the measurement

For a validation test of measurement of LNA of this research, this research could take a face, a convergent or a discriminant validation test. The face validation test, usually done by a group of judges or experts who read the measuring technique, investigates whether the measurement actually measures what its name suggests (Hoyle et al., 2002). To do this, I planned to consult expert groups about the appropriateness of the survey questions. The expert group was selected based on frequencies of being listed on a journal paper, such as IGLC (International Group of Lean Construction). For example, in IGLC 16th proceedings, the most frequently appearing person is Glenn Ballard (391 times), the second person is Professor Koskela (327), the third person is Professor Iris D. Tommelein (212), the fourth is Sven Bertelsen (118), and the fifth is Gregory Howell. They were to be the members of the expert group. However, I found they were too busy to review the survey measurement. Thus, this researcher developed the instrument in a more improvised way. The details are explained in the part explaining 'face validation test' of section 5.1.1.

A convergent validation test is to investigate the overlap between alternative measures that are intended to tap the same construct, which is an abstraction that needs to have concrete representation in order to be measured, but that has different sources of systematic error (Hoyle et al., 2002). This could be done relatively easily. Survey measurement and phone interview could be the different measurements for this test. When we ask basically the same questions with the two different measurements, and if the results are very similar, the convergent validation test results in desirable condition.

A discriminant validation test investigates the degree to which concepts that should not theoretically be related are not interrelated in reality (Trochim, 2006-b). For example, assuming an architect records a relatively high score in Set Based Design (SBD), but if he/she answers that each engineer participated in design process only after the previous specialists had finished their works, his/her answers are inconsistent with each other because the later part shows the design processes followed totally Point Based Design (PBD). In that case, we should investigate if the measurement is correctly made. For the discriminant test, this researcher inserted into the survey some heterogeneous questions that are different from those destined to measure Lean Construction as follows:

(a) To what degree a specialist in design started the design of his/her part only after the previous specialist finished its design
   <Reason> This method indicates PBD, the very opposite methodology to SBD.

(b) Whether or not one or some project managers were finally responsible for the total process design of Lean Construction.
   <Reason> This strategy is centralized control, as opposed to distributed control that Lean Construction employs.

Those questions for the discriminant test should show the trends opposite to those of other general questions supposed to measure the appropriate concept of Lean Construction.

A reliable measurement would give us the same result over and over again (Trochim, 2006-c). This research could take the test-retest strategy for reliability test. If we are fortunate enough to have a respondent who is willing to do the same survey twice, his/her answer will be used for reliability test. However, this did not happen.
4.5 Sampling issues

The only way we can be confident about generalizing from a sample to a population of interest is to draw a random sample from the population (Hoyle et al., 2000). However, if this research used a random sampling from the current construction industry to solve [Q1], the sampled group would not have enough cases that contain the features of Lean Construction to find causal inference between Lean degree and performance. The International Group of Lean Construction (IGLC) was founded in 1993 (http://iglc.net), the Lean Construction Institute was founded in 1997 (http://www.leanconstruction.org), and the Lean Construction Journal has been published since 2002. All these facts indicate that Lean Construction is a relatively new field, so that most construction companies probably do not know it, let alone use it. For this reason, this researcher adopts a purposive sampling on Lean projects instead of a random sampling. I measured implementation of Lean Construction including Incentives based on integration, Set Based Design, Value Stream Analysis, and Last Planner™ and measured project performance in the purposive sample in order to find a relation between Lean Construction and project performance.

Purposive sampling is widely used in studying unusual critical cases, such as identifying communities across the United States that have voted for the winner in past elections, or it is used in selecting key informants for ethnographic studies (Bernard, 2000). The targets of the purposive sample are those projects that already used Lean Construction. To find out the Lean Projects, I attended relevant conferences, such as those sponsored by the Project Production System Laboratory, or sent e-mails through relevant e-mail lists, such as the general IGLC group in Yahoo.

In order to answer [Q 2 and 3], which are directly related to testing this research hypothesis on the population of the Korean construction industry, this research adopts randomized sampling strategy, which enhances external validity. Of course, random sampling might not yield enough cases to test the hypothesis, as pointed out above. However, we need to bear in mind that a strong hypothesis testing is be done on the purposive sample comprised of Lean Projects outside of Korea and that this randomized sample is for diagnosing the Korean Construction Industry first based on the result of the survey on the purposive sample. The sampling strategy combining a purposive sample of Lean Projects and a randomized sample of Korean Projects complement defects of the other sample.

Before getting a random sample, I investigated features of the population, the Korean construction projects, in order to check if stratification of the random sample for this research is necessary. Successful stratification in a sample shows the internally homogeneous feature in every stratum with respect to the characteristics being studied, which means the differences of dependent variables between strata are significantly larger than those within strata (Hoyle et al., 2002). Again, the dependent variable of this research is project performance. If there are groups in the population of this research whose features induce significantly different performance relative to the rest of the population, the groups should be treated as strata. One of the most efficient ways to develop an insight on how to divide strata is to investigate the current project classification defined by the legal systems that have reflected the economic, political and social consensus of the nation.
There are three core South Korean Acts relevant to construction as follows.

(a) The Act on Contracts to which the State is a Party, which regulates how to make an estimated price, when and how to apply different project delivery systems, and how to bid and contract for public projects

(b) The Construction Technology Management Act, which regulates how to develop, maintain and disseminate construction technology, defines the construction processes, regulates how to determine kinds of project-delivery systems, and other matters relevant to construction technology

(c) The Framework Act on the Construction Industry, which defines kinds of works related to construction projects, how to register, and regulates relevant to subcontracting, how to manage construction sites, how to support small construction company, how to settle construction disputes, and matters relevant to penalties or fines.

There are important six criteria to categorize Korean construction projects according to the Enforcement Decree of the Act on Contracts to which the State is a Party, as Table 4-4 shows.

<table>
<thead>
<tr>
<th>Criteria of categorization</th>
<th>Classification of Construction</th>
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<tbody>
<tr>
<td>Methods of selecting Contractors</td>
<td>Competitive bidding based on minimal price.</td>
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<td>Competitive bidding with investigation of capability to construct.</td>
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<td>Design Build.</td>
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<td>Alternate Design Bid.</td>
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<td>Selecting contractors by the most economical values.</td>
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<td>Technical Proposal Bid.</td>
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<td>Technical Competition.</td>
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<td>Selecting contractors by assessing proposals and negotiations.</td>
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<td>Types of Price of Contracts</td>
<td>Lump-sum Price Contract.</td>
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<td>Unit-Price Contract.</td>
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<td>Types of Contracts depending on the number of contractors</td>
<td>Contracts with a consortium of several contractors.</td>
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<td>Contracts with one contractor.</td>
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<td>Methods of participating Bids</td>
<td>Bidding by general competition.</td>
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<td>Bidding by limited competition.</td>
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<td>Bidding by competition among appointed contractors</td>
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<td>Private contract without bidding</td>
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<td>Types of Contracts depending on the periods of Contracts</td>
<td>One-year contracts.</td>
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<td>Long-term continuous contracts.</td>
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<td>Continuous price contracts.</td>
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<tr>
<td>Types of contracts depending on the number of owners</td>
<td>Synthetic contracts with multiple governmental organizations as owners.</td>
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<td>General Contracts.</td>
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</tbody>
</table>
A project can be a combination of sub-items extracted from some of the six groups. The rules of combination are also defined in the same Enforcement Decree. Table 4-5 shows that there are 76 variations in the current contract. In fact, the total number of variation is 76+12=88 because Table 4-5 did not count the variations caused by Technical Competition (TC). I omitted TC because it is very similar to Technical Proposal Bid (TPB). The total number of variations caused by TPB is also 12. The detailed contents of representative project delivery systems are addressed in Chapter 6.

However, there are several problems in doing a perfect random sampling with 88 strata. First, we have no information about the real proportion of each stratum, from 1 to 88. Second, there are too many strata to sample from unless the number of cases sampled is very large.

Table 4-5: Kinds of the contracts of Korean public construction projects

<table>
<thead>
<tr>
<th>Methods of selecting contractor</th>
<th>Types of price of contracts</th>
<th>Types of contracts depending on number of contractors</th>
<th>Methods of participating bids</th>
<th>Types of period of contracts</th>
<th>Types of contracts depending on numbers of owners</th>
<th>Proportions to 1 sample in terms of number of projects</th>
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</thead>
<tbody>
<tr>
<td>Competitive bid with investigation (less 10 billion Korean won)</td>
<td>Lump sum price</td>
<td>Contract with Consortium</td>
<td>Bidding by competition (all projects)</td>
<td>1 year contract</td>
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<td>Bidding by limited competition (over 3 billion won)</td>
<td>1 year contract</td>
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<td>Competitive bidding with Minimum price (over 10 billion Korean won)</td>
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<td>Contract with consortium</td>
<td>Bidding by competition (all projects)</td>
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<td>Design-Build (over 30 billion won)</td>
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<td>Technical proposal bid (very technical and innovative projects in Sejong city and inno city)</td>
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<td>Private contract without competition (Projects under 200 million won)</td>
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<td>Contract with one contractor</td>
<td>Contract with consortium</td>
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<td>----------------------------------</td>
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<td>--------------------------</td>
<td>-----</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit price</td>
<td>Contract with one contractor</td>
<td>P75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit price</td>
<td>Contract with one contractor</td>
<td>P76</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Practically, Ministry of Land, Transport and Marine affairs of Korea (MLTM) uses 36 strata in the classification of construction projects (http://scmo.mltm.go.kr/intro.do, 2009). Similarly, it is very hard to find the portion of each stratum of the MLTM in the total population and the 36 strata are also too many for effective use with relatively small sample sizes.

Consequently, I concluded that the stratifications by the Korean Act system are not appropriate for this research, and decided that this research should set its own strata based on the theory of Lean Construction. In view of Lean Construction, the first criterion as a factor to influence project performance is separation between design and construction because many important concepts in Lean Construction are not available in a Design-Bid-Build (DBB) Project separating design and construction completely.

For example, DBB projects don’t allow contractors’ participation in product design and feasibility study. Subsequently, Set Based Design (SBD), which regards contractors’ input to product design/feasibility study as the utmost component toward success, is not possible in a DBB project. Of course, the architect of a DBB project can employ some techniques used in SBD, such as reviewing design alternatives or narrowing down the alternatives according to constraint analysis but any reduction of negative iterations achieved by the architect during the designing cannot be delivered to construction because contractors should review the design again based on the real conditions since the architect’s constraint analysis does not reflect real conditions which should have required contractors’ input. Thus, it is hard to say there is any influence of SBD, having been employed by the architect in designing, on the final project performance of the DBB project. In the same context, there cannot be integration of process design and product design in a DBB project either.

The degree of separation or integration between design and construction can make the survey instrument totally different if this research uses differently customized survey based on the respondents. A customized survey is important because it is hard to get all the information of a project from one person. An owner can provide information relevant to project performance but he/she might not be appropriate to tell about production control in the construction. A general contractor can provide information about both project performance and Lean tools having been used in the construction, but this amount of information is so big that the contractor may fail to complete the survey. Thus, this researcher decided to collect data from different persons on a project at the beginning.

However, this strategy can also lower the response rate because if one of the several respondents of one project does not complete his/her survey portion, all of other survey answers might be useless. In that case, I modified the survey forms in a way that the number of necessary respondents and the total number of questions for a project became less in order to increase the response rate.

That the survey should take on different forms according to the degree of integration/separation of design and construction advised us to take the integration of design and construction as a criterion making strata in the random sample for this research. Table 4-6 shows how different the survey measurement of this research might be according to whether a project is a DB or DBB.
**Table 4-6: Comparison between DBB and DB survey instrument**

<table>
<thead>
<tr>
<th>Survey type</th>
<th>Owner of Design-Bid-Build (DBB)</th>
<th>Architect of DBB</th>
<th>Contractor of DBB</th>
<th>Owner of Design-Build (DB)</th>
<th>Contractor of DB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contractors’ participation in feasibility study</td>
<td>n.a.</td>
<td>n.a.</td>
<td>No</td>
<td>n.a.</td>
<td>Possible</td>
</tr>
<tr>
<td>Contractors’ participation in product design</td>
<td>n.a.</td>
<td>n.a.</td>
<td>No</td>
<td>n.a.</td>
<td>Possible</td>
</tr>
<tr>
<td>Contractors’ participation in setting target cost</td>
<td>n.a.</td>
<td>n.a.</td>
<td>No</td>
<td>n.a.</td>
<td>Possible</td>
</tr>
<tr>
<td>Integration of product design and process design</td>
<td>n.a.</td>
<td>n.a.</td>
<td>No</td>
<td>n.a.</td>
<td>Possible</td>
</tr>
<tr>
<td>Incentives</td>
<td>n.a.</td>
<td>Possible</td>
<td>Possible</td>
<td>n.a.</td>
<td>Possible</td>
</tr>
<tr>
<td>Decomposition of target cost</td>
<td>n.a.</td>
<td>Possible (only design cost)</td>
<td>Possible</td>
<td>n.a.</td>
<td>Possible</td>
</tr>
<tr>
<td>Design to cost</td>
<td>n.a.</td>
<td>No</td>
<td>No</td>
<td>n.a.</td>
<td>Possible</td>
</tr>
<tr>
<td>Production control</td>
<td>n.a.</td>
<td>Possible</td>
<td>Possible</td>
<td>n.a.</td>
<td>Possible</td>
</tr>
<tr>
<td>Cost</td>
<td>Two separate cost for design and construction</td>
<td>n.a.</td>
<td>n.a.</td>
<td>Hard to separate the cost of design and construction</td>
<td>n.a.</td>
</tr>
<tr>
<td>Duration</td>
<td>Same to the right above</td>
<td>n.a.</td>
<td>n.a.</td>
<td>Same to the right above</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

DB and DBB are located near to each end of the spectrum arraying Project Delivery Systems (PDS) from the most separating to the most combining design and construction. In fact, there are many other project delivery systems in the spectrum. For example, Design-Bid-Build, Construction Management (CM) for fee, CM at risk, Portland Method, and Design Sequencing can be regarded as PDSs separating design and construction contractually to a certain degree, while Design-Build, Project Alliance, and Integrated Project Delivery can be the ones combining design and construction contractually to a certain degree. For information, I quoted Table 2 of Cho et al. (2010) as Table 4-6 to explain the aforementioned PDSs briefly.
<table>
<thead>
<tr>
<th>Name of PDS</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agency Construction Management (Agency CM)</td>
<td>There is a separate consultant as CM, other than architect and contractor, who is not responsible for construction cost risks.</td>
</tr>
<tr>
<td>Multi prime approach of Design-Bid-Build</td>
<td>A CM manages multiple contractual relations between the owner and several contractors instead of general contractor but is not responsible for the construction cost.</td>
</tr>
<tr>
<td>Construction Management at Risk (CM @ R)</td>
<td>The General Contractor (GC), as a CM, is responsible for cost overrun over Guaranteed Maximum Price (GMP), and is involved in the pre-construction processes.</td>
</tr>
<tr>
<td>Portland Method</td>
<td>A kind of CM @ R, but the contractual cost, named as Estimated Reimbursable Cost (ERC) is determined later than GMP, usually determined in the early phase of the design, in order to increase cost certainty.</td>
</tr>
<tr>
<td>Design Sequencing</td>
<td>GC can start construction of a phase as soon as the design of the phase is completed, while the design of the next phase is ongoing. But, the GC usually does not participate in making the design of the project.</td>
</tr>
<tr>
<td>Early Involvement of Contractor and Target Pricing (EIC)</td>
<td>A kind of DB. But it lets the GC get involved in the pre-design phase and uses target pricing with fiscal incentives combined with an open account instead of lump sum price, used in a usual DB.</td>
</tr>
<tr>
<td>Project alliancing</td>
<td>It selects the whole project alliancing team, including architect, GC and key special contractors based on criteria other than minimum price for construction at the beginning of the project, uses the Limb 3 principle(^\text{40}) to set the pain/gain share mechanism, and adopts an open account and unanimous decision making system.</td>
</tr>
<tr>
<td>Integrated Project Delivery (IPD)</td>
<td>A single agreement among all participants, waiver of the right of all participants to sue any of the other members until the completion of project, early involvement of specialty contractors in the design phase, and incentives and disincentives with target price.</td>
</tr>
<tr>
<td>Design-Build and Design-Bid-Build</td>
<td>Too famous to be specified.</td>
</tr>
</tbody>
</table>

The purposive sample comprised of ‘Lean projects’ did not take this stratification because there were neither sufficient cases nor definite lines separating strata. In fact, the PDSs arrayed in Table 4-7 can take on mixtures of the strata. For example, CM@R is usually regarded as a representative system separating design from construction but I found some cases, having used CM@R, which recorded themselves as ones combining design and construction in the purposive sample, which shows kind of PDS is not an absolute criteria to determine whether a project combines or separates design and construction.

\(^{40}\) Limb 1 cost: all direct costs of the project and project specific overhead incurred by the alliance team members; Limb 2 fee: corporate overhead and profit, a fixed lump sum set as percentage of the target cost, this is the maximum financial loss of the non owner parties; Limb 3 fee: distributed fee among members of the alliance team from the total difference between Limb1 cost and target cost according to the predetermined principles.
However, as for Korean industry, we don’t need to consider this ambiguity because there are only two forms in the nation; Design-Bid-Build or Design-Build. Table 4-4, classifying overall Korean construction projects, seems to be very difficult, but the difficulty is due to how to contract or how to procure the contractor, not due to the degree of integration between design and construction. Thus, the random sample from Korea took this stratification.

So far, I have discussed why the first criterion stratifying the randomized sample from the Korean Construction Industry should be the integration of design and construction. The next criterion is whether a project is a public one, which is also induced from the Lean Ideal to provide a custom product exactly fit for the purpose and delivering it instantly with no waste (Ballard et al., 2007), because this criterion reflects the attitude of an owner toward project performance.

If an owner of a project is a private person or organization, every goal of all participants would be basically aligned to reduce the owner’s cost and time. However, if the owner is a public agency, we cannot expect the same intensity toward cost or time reduction as we see in private owners because the resources (money and time) do not belong to the agency. As everyone knows, the source of funding for a public project is the taxes collected from the general people of the state. In summary, the two criteria stratifying the Korean sample of this research are 1) whether design and construction of a project are combined, and 2) whether a project is a public project.

The next concern is how to get members of the Korean randomized sample as well as those of each stratum of the sample. To do this, I investigated a web site, named ‘Knowledge Information System of Construction Industry’ (KISCON: http://www.kiscon.net/), which is supervised by the Korean government and contains information about Korean construction projects. The 22nd provision of the Framework Act on the Construction Industry and the 26th provision of the Enforcement Decree of the Framework Act on the Construction Industry force the contractor who is awarded by a project (over 100 million Korean won) to provide the owner with certain information of the project, such as project name, and contractual cost/duration, through KISCON within a month after contracting.

After some investigation of KISCON, I succeeded in gathering a list of names and contractors’ names of all the projects in which contractual prices were over 10 billion Korean won and which were launched after the year 2003 and finished by 2009. The total number of cases in the population is 5,880. According to the aforementioned strata, I categorized all the projects into public Design-Bid-Build projects (1,958 cases), public Design-Build/Alternate Design-Bid projects (312), private Design-Bid-Build projects (3,409), and private Design-Build/Alternate Design-Bid projects (5880-1958-312-3409=201). Then, I selected 100 projects from each stratum randomly, with the logic that if the (random ( ))41 > (100/the total number of cases in a stratum) using MS EXCEL program in order to get a random sample. I contacted the 400 projects in which there were 100 projects per each stratum and got 86 projects as the entire sample finally.

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41 Random ( ) order in MS EXCEL produces random values from 0 to 1.
4.6 Finalizing research design

Lieberman (2005)’s research design, represented in Figure 4-1, can be transformed to a customized design to fit the purpose of this research, as Figure 4-6 describes. The research design in Figure 4-6 describes four phases of survey. The first, second and third phases’ surveys employ purposive samples from the projects that are known to have implemented Lean Construction while the fourth phase’s survey adopts a stratified and randomized sample from Korea because the purpose of each phase is different.

The first phase’s survey takes on a pilot survey or a preliminary survey to modify the original survey instrument (A.2). In this phase, I asked the respondents whether there are any problems in understanding the survey and investigated whether the measurement is correctly addressed. For this purpose, the respondent should be able to answer some technical questions about Lean Construction. Thus, I gathered the member of the survey sample among the projects that were known to have implemented Lean Construction or similar concepts by attending some conferences related to Lean Construction or by sending e-mails of relevant e-mailing list.

The second phase’s survey also aims for modification of the survey after the first phase but it takes case studies for the purpose. Using the cases collected by the same purposive sampling as having been used for the first phase’s survey, the survey in the second phase produces a regression model between Lean Construction and performance. Subsequently, I selected some cases based on the distance from the regression model. One of the case studies is for model testing and the other is for model building as we can see in Figure 4-6. The case study for model testing selects cases on or very near to the regression line, which follows Most Similar Same Outcome (MSSO) selection strategy, as discussed in Table 4-1, is used to support the fitness of the regression line by Process Tracing.

The case study for model building using the cases off or far from the regression line, which follows Most Similar Different Outcome (MSDO) strategy, discussed in Table 4-1, is used to find out what caused the variation of performance, which cannot be explained by the regression model. Another thing we should check here is the second phase’s survey uses the cases from Korea because the modified survey version that this phase produced is used in the fourth phase’s survey on the Korean industry. There are few Korean projects that have experienced Lean Construction so that I contacted a group of projects that implemented similar innovative concepts such as collaborative decision in design or schedule among construction parties as pseudo-Lean projects.

The third phase’s survey tests the research hypothesis on the purposive sample comprised of Lean Projects from outside of Korea. In this phase, we can see if Lean Construction improves performance. If the research hypothesis is supported well by this phase, this research can continue diagnosing the Korean industry in the fourth phase.

The fourth phase’s survey uses a randomized and stratified sample comprised of Korean projects. A random sample is the most appropriate form to make a generalized conclusion. This research found unique appearance of the nation’s industry compared to the industry measured in the third phase and interpreted the appearance in term of Lean Construction and in terms of Korean legal/social contexts. This diagnosis helped me produce more practical and feasible policy recommendations for the nation’s industry, which was the last step of this research.
Select Lean Projects

The First Phase

Revising Survey

The Second Phase

Model Testing
Case study

Select Lean Projects including Korean ones

Model Building
Case study

See if Processes are supported by theory

Find Additional Causal factors

Select Lean Projects from outside of Korea

The Third Phase

Hypothesis Testing

The Fourth Phase

Select Korean Projects by a random sampling

Diagnosing the industry

Policy Recommendation

Stop

Figure 4-6: Final research design
CHAPTER 5: DATA COLLECTION AND ANALYSIS

5.1 Modification of survey at the beginning

5.1.1 Face validation test

As mentioned section 4.4, this research planned to take a face validation test, a convergent and discriminant validation test to check the validity of the survey measurement. While a discriminant validation test\(^{42}\) and a convergent validation test are usually done after data collection, a face validation test is checked before the data collection (Hoyle et al., 2002).

Due to its nature, a face validation test is usually done by a group of judges, who are experts in the relevant field (Hoyle et al., 2002). Thus, I investigated who appeared most frequently in the 16\(^{th}\) International Group for Lean Construction Conference (IGLC) proceedings in order to locate them as the expert group. The counting result told that the most frequent appearing person is H. Glenn Ballard (391 times), the second is Lauri Koskela (327), the third is Iris. D. Tommelein (212), the fourth is Sven Bertelson (118), and the fifth is Greg Howell (117). However, it did not take long for me to conclude that they would be too busy to review all the survey instruments. The alternate plan was to ask several PhD students, who had studied Lean Construction for years.

The total number of PhD students, participating in the face validation test, was four. These experts gave practical tips in making survey questions as follows.

(a) Make survey as short as possible, delete unnecessary words and use graphical expressions to reduce the time during which respondents think to choose the answers.

(b) Make different survey format according to the respondents’ position. (e.g., the survey sent to owner should have a different form from those sent to contractor.)

(c) Use online survey instead of paper based mail survey.

(d) Make some concepts more specific and clearer. (e.g., Constraint analysis in Lean Construction should have different levels according to the timely distance between the point of the constraint analysis of a work and the execution of the work.)

(e) Make some terminology more generalized for general construction specialists’ easier understanding. (e.g., Work structuring\(^{43}\) should be converted and decoded into several items which can be understood by general construction technicians.)

(f) Make sure that people would be willing to give the data, which might be confidential.

(g) Use more correct words in explanation. (e.g., Use ‘conceptual design’ instead of ‘drawing list preparation,’ ‘design development’ instead of ‘design and drawing list updates’ and ‘construction document’ instead of ‘design and drawing report print out.’)

(h) Make survey measurement objective as much as possible. A subjective opinion-based survey probably would not be recognized as academically valuable one.

\(^{42}\) This investigates the degree to which concepts that should not be related theoretically are not related in reality (Trochim, 2006)

\(^{43}\) For easier understanding, it is to decide contingency of works duration, size of resource storage between consecutive works, time buffer between works proportional to contingencies, materials’ amount delivered between works, materials physical conditions, production rate of materials, prerequisite conditions and sequences of works, and so on. In Lean Construction, it is possible only while integrating product design and process design (quoted from the interviews with the expert group comprised of PhDs)
(i) Be prepared for the case, in which most of the answers to the survey questions for the Korean construction industry are ‘No’. Lean Construction can be new concept in that nation.

In addition to the aforementioned consultation of the PhD students, I consulted some professors, who had taught research methodology, in order to get more general recommendations. The followings are the summary.

(a) Consider the coding, the analysis and the response rate while making the survey questions.
(b) Use the general terminology used in sociology (e.g., Never, Rarely, Sometimes, often and always in measuring frequency).
(c) Do a pilot survey before the main survey.
(d) Select only the concepts that are really needed to get what you want. Too many questions just harm the response rate.
(e) Use appropriate strategies between Likert types or Yes/No types.
(f) Make the questions more conversational and more familiar.
(g) Make skip logics lest certain respondents should answer unnecessary questions.

The recommendations from PhD students in Lean Construction and professors in Research Methodology helped me modify the original survey instrument. In addition, I did some pilot surveys using the modified survey instrument based on the recommendations above. The pilot surveys asked them to answer the questions regarding some construction projects that they had already known well. The followings are the findings from the pilot surveys.

(a) English in the survey might need to be revised but most of the questions are understandable.
(b) Some questions are hard to answer\(^{44}\).

\(^{44}\) Sometimes, similar suggestions have been raised by the respondents of reference projects. They complained that some questions, expressed with lean construction terminologies, were hard to understand. All of those problematic parts have been revised to meet the customers.
5.1.2 During Data collecting at the beginning

After the modification by the face validation test, the survey was disseminated to a purposive sample comprised of Lean projects. This chapter describes the modification right after starting of the data gathering. Some respondents advised me to modify the survey for easier understanding. This modification had been continued until the end of the first phase of data gathering, which is discussed in section 5.2. Resultantly, this small number of projects became the references for the afterward surveys. The comments from the respondents during the first phase as follows.

(a) In the survey for the architect of a Design-Bid-Build (DBB) project, description of the phase scheduling in making the product design is not easy to understand. For example, ‘handoffs’ and ‘product design’ are not familiar words in the normal architect’s world.

(b) In the survey for the architect of a DBB project, the modification of a schedule by the schedule in the right below is hard to be understood.

(c) Those projects that are very complex and different from general building projects, such as an oil plant construction, are hard to be measured by the unit cost.

(d) Sometimes, it is hard to choose whether a project combined or separated design and construction. Thus, the survey for the project separating design and construction should have flexibility to deal with integration of design and construction to a certain degree.

(e) This survey should clarify the meaning of the gross square footage.

(f) There seems to be a mistake in the skip logics of the online survey. For example, even though a general contractor did not participate in feasibility study, specialty contractors can participate in design. However, this survey cannot deal with such cases.

In addition to modification, some new questions were purely added during this reference data gathering. Some added questions are as follows.

(a) This survey added the questions simply asking the type of project delivery system of a project to address the contractual status of the project with more accuracy and to be compared with the answers from respondents.

(b) A question asking subjective overall satisfaction is added as reference information to be used in comparison with quantitative project performance and the question requesting suggestion for policy innovation is added for diagnosis with more accuracy and for better recommendation for the industry’s policy.
5.2 First phase of data collection

5.2.1. How to find members of the Lean projects’ sample

I attended several conferences relevant to Lean Construction in order to contact the potential survey respondents as follows.

(a) VSM-12 California Health Care Facility on October 28th 2009 held by Project Product Systems Laboratory (P2SL: http://p2sl.berkeley.edu/)

(b) P2SL-Lean Construction Institute (LCI: http://www.leanconstruction.org) Lean Design Forum on January 21st 2010 held by P2SL

(c) Conference held by the Research Team 271 of Construction Industry Institute (CII: https://www.construction-institute.org/scriptcontent/index.cfm) on April 13th 2010

(d) P2SL annual conference on April 27th 2010

I collected some e-mail addresses from the aforementioned conferences so that I got information from 40 projects. However, the number, 40, did not represent the number of the projects available for the data analysis. The minimum condition for the analysis is that there should be at least two responses per a project from the owner and from the contractor. The number of the projects available for the data analysis, which had been collected from October 27, 2009 to October 10, 2010, was only 11. That was too small a number of projects to be used for the data analysis and I concluded that complicated survey structure could harm the response rate. This conclusion drove the modification of the survey for the second phase of data gathering, which was discussed in section 5.3

5.2.2 Supplementary information in the first phase

There were five different on-line surveys in the first data gathering phase. Even though this research got only the eleven projects that were available for the statistical analysis, each survey received a bigger number of respondents than eleven. In this chapter, I addressed the information that was not used in statistical analysis. This supplementary information showed several interesting features of the projects

5.2.2.1 Survey for an owner of a project separating design and construction

The total number of the responses in this category is 19. Design-Bid-Build (DBB) and Construction Management at Risk (CM@R) belonged to this category. The following listed items are the summary of the responses in this category.

(a) The most popular bid feature that 41.67% of the owners chose as the most important bid feature in selecting the contractors for their projects is ‘cost submitted by bidder.’ The second most popular bid feature is ‘performance of the past similar projects’ chosen by 13.33% of the owners

(b) The most popular bid feature that 60% of the owners chose as the most important bid feature in selecting the architects for their design is ‘understanding of the project.’ The second popular bid feature is ‘performance of the past similar design’ chosen by 30% of the owner. ‘cost submitted by bidder’ or ‘duration submitted by bidder,’ which had been chosen as the most important bid features in selecting contractors before, did not take higher rankings as the most important bid feature to the owners in this category.
(c) 43.8% of the owners disagreed or strongly disagreed that a contractor would inflate the expected cost/duration of a project for his/her own benefits or for more buffers to cover the future uncertainty if he/she participated in the design. Figure 5-1 is the summary of the results.

(d) 50% of the owners felt that the existing methods having procured the contractors of their projects were not appropriate for maintaining the market competitiveness due to lack of capability to select the most competent builders. Figure 5-2 is the summary of the results.
(e) 78.5% of the owners agreed that if the performance of past similar projects became an absolute criterion evaluating bids, every contractor tried to achieve better performance than that specified in contract. Figure 5-3 is the summary of the results.

![Figure 5-3: DBB/CM@R owners’ recognition of performance as an absolute bid feature](image)

(f) Figure 5-4 is summary of the causes interfering performance improvement. The most popular reason is ‘the architects’ being reluctant to change traditional methods’ chosen by 37% of the owners. The second one is ‘the time consuming government administration’ chosen by 27% of the owners. This question allowed multiple choices so that a cause might be chosen more than once.

![Figure 5-4: Causes interfering performance improvement in view of DBB/CM@R owners](image)
In conclusion, the owners of DBB/CM@R projects tended not to agree that contractors would inflate expected cost/duration if they participated in the designs, to agree that the existing procurement of contractors, which they had used for their projects, lacked the capability to select appropriate bidders to a certain degree, and to agree that the performance of past similar project would encourage every contractor to pursue better performance than that specified in a contract if it were an absolute bid-evaluation criterion.

Interestingly, the owners in this category recognized ‘architect’s being reluctant to change the traditional way’ as the most harmful factor disturbing performance improvement. This is different from the responses from contractors, which was discussed in Ch. 5.2.2.2.

5.2.2.2 Survey for a contractors of a project separating design and construction

I collected 13 responses in this category. Design-Bid-Build (DBB), Construction Management at Risk (CM@R) and Construction Management (CM) for fee belong to this category. The summary of the responses is as follows.

(a) Contrary to the owners, the contractors tended to believe that an owner would request more works than necessary if the design was not specific enough. In the owners’ survey, 25.1% (Figure 5-1) of the respondents disagreed (or strongly disagreed) that a contractor will inflate the expected cost/duration of a project if the contractor participates in the design of the project while 18% of the contractors disagreed (or strongly disagreed) that owners will demand more works than necessary if the design is not concrete enough. Figure 5-5 is the summary of the results.

![Figure 5-5: DBB/CM@R/CM for fee’s contractors’ distrust in owners](image-url)
(b) 56% of the contractors felt that the current procurement of contractors for a project were not appropriate for maintaining the market competitiveness due to lack of capability to select the most competent builders. Figure 5-6 is the result.

Figure 5-6: DBB/CM@R/CM for fee’s contractors’ recognition of problems in the current procurement of contractors

(c) 54% of the contractors agreed that if past project performance is an absolute criterion of awarding a bid, every contractor tries to achieve better project performance than that, which is specified in the contracts of the current project. Figure 5-7 is the summary of the results.

Figure 5-7: DBB/CM@R/CM for fee’s contractors’ recognition of performance as an absolute bid criterion
(d) Figure 5-8 is a summary of the causes, interfering improvement of performance, in view of the contractors. The most popular cause is ‘owners’ being reluctant to change.’ (100%) The second one is ‘architects’ being reluctant to change.’ (62.5%) This question allowed multiple choices so that a cause might be chosen more than once.

![Figure 5-8: Causes harming performance in view of DBB/CM@R/CM for fee’s contractors](image)

In conclusion, contractors of DBB/CM@R/CM for fee projects recognized ‘owners’ being reluctant to change’ as the worst factor interfering performance and believed the owners will give more works than necessary if the design is not specific enough. Similar to the owners’ responses, the contractors also believed that performance should be an absolute criterion in selecting the contractor for a project in order to maintain the market competitiveness.

Judging from the responses from the owners and from the contractors, having the contractors, who have been selected based on the past performance of the similar projects, participate in design could be the solution to the problems that both of them pointed out. The owners thought that there were problems in the architects’ ways of design and that the contractors would not make problems when they participated in design. Then, why don’t they have contractors participate in the design instead of consigning all designs to architects? The contractors needed the detailed designs made by owner as proofs lest the owner should demand overworks. In addition, they thought the most problematic factor was ‘owners’ being reluctant to change’. In my opinion, the contractors’ thoughts contradicted each other. The more specific is a design in a contract the more does the owner stick to the design. The more does an owner stick to a design the more is he/she reluctant to change. The only solution is that contractors participates in the design of a project and take the responsibility to build the project according to their design.
5.2.2.3 Survey for an architect of a project separating design and construction

The total number of responses was 16. The summary of the responses is as follows.

(a) Interestingly, 78% of the architects disagreed or strongly disagreed that a contractor would inflate the expected cost or the expected duration of a project if he/she participated in the design of the project. This also supports the conclusion that contractors should participate in design in the late part of section 5.2.2.2. Figure 5-9 is the summary of the results.

![Figure 5-9: DBB/CM@R/CM for fee architects’ distrust in contractors](chart)

(b) All architects agreed that if past design performance is an absolute criterion of awarding a bid, every architect tries to achieve better performance than that specified in a contract. It seems to be that the more does a work need technological aspects, the more do people prefer the selection of bid based on past performance. As shown in 5.2.2.1, the owners also recognized past performance of similar design as the second most important bid feature. (The first important feature is ‘architects’ understanding of the project’). Figure 5-10 is a summary of the results.

![Figure 5-10: DBB/CM@R/CM for fee architects’ recognition of on performance as an absolute bid criterion](chart)
(c) Figure 5-11 is a summary of the causes interfering performance in view of the architects. The worst cause is ‘owners’ being reluctant to change from traditional ways’ and the second and the third causes are ‘general contractors’ being reluctant to change’ and ‘specialty contractors’ being reluctant to change’ respectively.

Figure 5-11: Causes harming performance in view of DBB/CM@R/CM for fee’s architects

5.2.2.4 Survey for an owner of a project combining design and construction

The total number of responses in this category is 10. Design-Build (DB), Early Contractor Involvement and target pricing (ECI) and Integrated Project Delivery (IPD) belong to this category. The summary of the responses is as follows.

(a) The most popular bid feature, which 42.9% of the owners pointed out as the most important feature in selecting contractors for their projects is ‘bidders’ understanding of the project.’ The second most popular feature regarded as the most important bid feature was ‘promised duration of the project,’ which 33.3% of the owners pointed out.

(b) 57.2% of the owner disagreed or strongly disagreed that a contractor would inflate the expected cost/duration if he/she participated in a design for his/her own benefits or for more the buffers to cover the future uncertainty. The summary is Figure 5-12.
(c) 43% of the owners agreed or strongly agreed that there were problems in the procurement of contractors for their projects in maintaining the market competitiveness. In the previous chapter, 50% of the DBB/CM@R/CM for fee’s owners agreed or strongly agreed that there were problems in the procurement of the contractors for their projects. Figure 5-13 is the summary of the results.
The most popular bid feature that the owners of the DBB/CM@R/CM for fee projects pointed out as the most important feature in selecting their contractors was ‘the price submitted by the bidders’ and the most popular bid feature chosen by the owners of the DB/EIC/IPD projects was ‘the duration submitted by the bidders.’

The owners of both the projects integrating and the projects disintegrating (design and construction) agreed that there were problems in the procurement of appropriate contractors for their projects. Judging from this, selecting contractors based on the bid cost or bid duration does not seem to guarantee project performance as promised in the bids. This interpretation also supports my opinion that contractors for a project should be selected based on the performance of past similar projects.

(d) 85.8% of the owners agreed or strongly agreed that every contractor tries to achieve better performance than that specified in a contract if the performance of past similar projects is an absolute bid evaluation criterion for a project. Figure 5-14 is the summary.

(e) 100% of the owners pointed out ‘time consuming government administration,’ ‘contractors’ being reluctant to change from traditional ways’ and ‘architects’ being reluctant to change traditional ways’ as the main culprits harming performance with the same importance.
5.2.2.5 Survey for a contractor of a project combining design and construction

The total number of responses collected through this survey is 15. The summary is as follows.

(a) 60% of the contractors agreed or strongly agreed that an owner would demand more works than necessary if the design was not specific enough. This is similar to the answers of the DBB/CM@R/CM for fee projects’ contractors. Figure 5-15 is the summary.

Figure 5-15: DB/EIC/IPD contractors’ distrust in the owner

(b) Most contractors didn’t agree that the existing procurement of contractors was harmful to maintain the market competitiveness. Their answers are evenly distributed between agreement and disagreement. Figure 5-16 is the summary.

Figure 5-16: DB/EIC/IPD contractors’ recognition of problems in the current procurement of contractor
(c) 80% of the contractors agreed or strongly agreed that if project performance became an absolute bid evaluation criterion, every contractor would try to achieve better performance than that specified in a contract. Figure 5-17 is the summary.

![Figure 5-17: DB/EIC/IPD contractors’ recognition of performance as an absolute bid criterion](image)

(d) All contractors pointed out ‘owners’ being reluctant to change traditional ways’ as the most popular cause interfering with the project performance. The second most popular cause was ‘architects’ being reluctant to change.’ Figure 5-18 is the summary.

![Figure 5-18: Causes harming performance in view of DB/EIC/IPD contractors](image)
5.2.2.6 Conclusion of section 5.2.2

The conclusions are summarized as follows.

(a) The procurement of a contractor based on the competitive bidding based on the least price might be problematic in terms of the market competitiveness.

(b) The procurement of a contractor based on the performance of past similar projects might be helpful to maintain the market competitiveness because every contractor would try to achieve better performance than that specified in a contract.

(c) A contractors’ participation in a design could be a solution of ‘owners’ reluctance to change the traditional way’ and ‘contractors’ reluctance to change from the traditional way’, which were pointed out as the causes harming project performance, because the two parties would share the responsibility for the performance rather than sticking to the design having been made far before the construction. In addition, the owners participated in this phase’s survey didn’t think that a contractor would inflate the expected cost/duration of a project if he/she participated in the design.
5.2.3 Findings from the eleven projects in the first phase

5.2.3.1 Structure of scoring the eleven projects

The scoring methodology is almost the same as what Figure 4-4, Figure 4-5 and Table 4-3 describe. Some differences are as follows.

(a) This phase did not consider the implementation of Lean Construction in the ‘design’ of DBB/CM/R/CM for fee projects.

(b) This phase did not consider the performance indicator of the ‘design’ of DBB/CM/R/CM for fee projects.

(c) This phase did not consider the performance indicators other than the sum of the cost reduction and the schedule reduction ratio of a project.

The reason to exclude measuring the variables of the design in DBB/CM/R/CM for fee projects, which are mentioned in (a) and (b), is that I could not get the relevant responses from the architect of the projects, whose owners and contractors had responded to the survey. To do an appropriate analysis of DBB/CM/R/CM for fee projects with this survey in the first phase, I needed three responses from the owner, the contractor and the architect of a project. However, it frequently happened that I could not get the architect’s response of a project when I received the responses from the contractor and the owner of the project. Thus, I used only the owners’ responses and the contractors’ responses in this phase so that I decided not to measure the performance of the design of any project.

The reason to exclude other performance indicators other than the sum of the cost reduction and the schedule reduction of a project, as explained in (c), is similar to the reason addressed in the right above paragraph. I had expected to get data about a safety measurement and a unit cost as the performance indicators as I planned in Table 3-21. But, most of the respondents were reluctant to reveal too much information about such detailed performance indicators as a number of safety accidents or a unit cost. The only available performance indicators were cost reduction and the schedule reduction, which were specified in Table 3-21. Finally, I decided to use the one performance indicator that summed the cost reduction and the schedule reduction of a project to represent a project performance in a more integrated way. Table 5-1 identifies the component variables including incentives, set based design, value stream analysis, Last Planner™, and performance indicator, going into each index and summarized how each index was constructed and scored.

5.2.3.2 Statistical analysis using the eleven projects

(a) Performance vs. Lean Construction

The dependent variable of this research hypothesis is performance and this is represented as the sum of cost reduction ratio (%), \([(\text{approved budget-actual cost/actual cost})\times100\], and the schedule reduction ratio (%), \([(\text{approved schedule-actual schedule/actual schedule})\times100\]. If there were a cost overrun or a schedule overrun, the dependent variable would take on a value below zero. Sometimes, a cost reduction recorded below zero, which meant a cost overrun, but if the schedule reduction excelled the absolute value of the cost overrun, the some of the two, the performance indicator was a positive score. The range of dependent variable was from -1.786 to 29.412. This is not surprising because an approved budget/schedule already reflected the change orders that the owner had approved so that the actual cost/the actual schedule should be less than equal to those approved ones in usual cases. On the contrary, an initial contractual cost/schedule that was used in the Korean projects instead of an approved budget/schedule did not reflect the change orders approved by the owner. Thus, most of the Korean projects’ performance indicators took on the score below zero in Chapter 5.4. The independent variable is ‘the degree of the implementation of Lean
Construction,’ which is the sum of the score of the answer to each question measuring Lean Construction that is comprised of Incentives, Set Based Design, Process improvement through Value Stream Analysis and the production control system called as ‘Last planner™.’ For more detail, see Table 5-1.

Table 5-1: Scoring structure in the first phase.

<table>
<thead>
<tr>
<th>Systemized Concepts</th>
<th>Indicators; answer type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Incentives</strong></td>
<td></td>
</tr>
<tr>
<td>(1) General Contractor (GC)’s investigation of the best practices before Calculation of the expected cost of the project; Yes/No.</td>
<td></td>
</tr>
<tr>
<td>(2) GC’s participation in feasibility study; Yes/No.</td>
<td></td>
</tr>
<tr>
<td>(3) % of Specialty Contractor (SC)s participating in feasibility study; Percentage.</td>
<td></td>
</tr>
<tr>
<td>(4) Existence of Target Cost (duration) less than the expected cost (duration); Yes/No.</td>
<td></td>
</tr>
<tr>
<td>(5) GC’s participating in setting Target Cost (duration); Yes/No.</td>
<td></td>
</tr>
<tr>
<td>(6) % of SCs participating in setting Target Cost (duration); Percentage.</td>
<td></td>
</tr>
<tr>
<td>(7) Existence of incentives in cost reduction; Yes/No.</td>
<td></td>
</tr>
<tr>
<td>(8) Existence of incentives in time reduction; Yes/No.</td>
<td></td>
</tr>
<tr>
<td>(9) Existence of incentives in other performance improvements; Yes/No.</td>
<td></td>
</tr>
<tr>
<td>(10) GC’s participating in setting incentives; Yes/No.</td>
<td></td>
</tr>
<tr>
<td>(11) % of SCs participating in setting incentives; Percentage.</td>
<td></td>
</tr>
<tr>
<td>(12) Performance assessment after completion; Yes/No.</td>
<td></td>
</tr>
<tr>
<td>(13) Performance assessment open to the market; Yes/No.</td>
<td></td>
</tr>
<tr>
<td>(14) Using Open account; Frequency.</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Set Based Design</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Start of GC’s participation in a project; there are 5 steps. Business planning gets 1, Feasibility study gets 4/5, Beginning of general design gets 3/5, During design gets 2/5, and After design gets 1/5.</td>
<td></td>
</tr>
<tr>
<td>(2) Start of SCs’ participation in a project; same to the right above.</td>
<td></td>
</tr>
<tr>
<td>(3) % of SCs participating in design; Percentage.</td>
<td></td>
</tr>
<tr>
<td>(4) GC’s decomposition of target cost into components of a project; Yes/No.</td>
<td></td>
</tr>
<tr>
<td>(5) % of SCs participating in the decomposition of the target cost; Yes/No.</td>
<td></td>
</tr>
<tr>
<td>(6) Designers’ consulting other engineers; Frequency</td>
<td></td>
</tr>
<tr>
<td>(7) Designers’ consulting GC; Frequency</td>
<td></td>
</tr>
<tr>
<td>(8) Designers’ consulting SCs; Frequency</td>
<td></td>
</tr>
<tr>
<td>(9) Review of design alternatives as many as possible; Frequency</td>
<td></td>
</tr>
<tr>
<td>(10) Narrowing down Design alternatives based on constraint analysis; Frequency.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process improvement through Value Stream</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Concurrent design of product and process; Frequency.</td>
<td></td>
</tr>
<tr>
<td>(2) % of SCs participating in process design; Percentage.</td>
<td></td>
</tr>
<tr>
<td>(3) Minimizing batch size of material while process design; Frequency.</td>
<td></td>
</tr>
</tbody>
</table>
## Analysis

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>(4)</td>
<td>Standardization of material/process/or component while process design; Frequency.</td>
</tr>
<tr>
<td>(5)</td>
<td>Inventory management while process design; Frequency.</td>
</tr>
<tr>
<td>(6)</td>
<td>Preassembly before installation of material/component while process design; Frequency.</td>
</tr>
</tbody>
</table>

## Last Planner™

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>(1)</td>
<td>% of handoffs defined before a phase; Percentage.</td>
</tr>
<tr>
<td>(2)</td>
<td>% of SCs participating in a phase schedule; Percentage.</td>
</tr>
<tr>
<td>(3)</td>
<td>Correcting the master schedule by a phase schedule about the wrong decision made in the master schedule.</td>
</tr>
<tr>
<td>(4)</td>
<td>Number of aspects considered in constraint analysis; Number.</td>
</tr>
<tr>
<td>(5)</td>
<td>Timing of constraint analysis (more than 6 weeks before gets 0.5, from 1 to 6 weeks before gets 1, and less than 1 week before execution gets 0.5).</td>
</tr>
<tr>
<td>(6)</td>
<td>% of SCs doing constraint analysis; Percentage.</td>
</tr>
<tr>
<td>(7)</td>
<td>% of SCs doing a first run study; Percentage.</td>
</tr>
<tr>
<td>(8)</td>
<td>Correcting a phase schedule by a constraint analysis about the wrong decision made in the phase schedule; Frequency.</td>
</tr>
<tr>
<td>(9)</td>
<td>% of SCs investigating the next worker’s readiness; Frequency.</td>
</tr>
<tr>
<td>(10)</td>
<td>% of processes having instantaneous communication tools with adjacent ones; Percentage.</td>
</tr>
<tr>
<td>(11)</td>
<td>Correcting wrong decision made in constraint analysis during weekly work plan; Frequency.</td>
</tr>
<tr>
<td>(12)</td>
<td>% of the causes of weekly work plans' failures, being removed before executions of similar plans; Percentage</td>
</tr>
<tr>
<td>(13)</td>
<td>% of SCs investigating whether the causes of similar weekly work plans were removed before their works’ executions</td>
</tr>
</tbody>
</table>

## Performance indicator

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>Cost reduction + Schedule reduction = (Approved budget-Actual cost)/Actual cost×100+(Approved schedule-Actual schedule)/Actual schedule×100</td>
</tr>
</tbody>
</table>

Figure 5-19 shows the scatter plot and the regression mode between the two variables. The regression line is project performance \((Y \text{ in Figure 5-19}) = 0.58 \times \text{implementation of Lean Construction (X in Figure 5-19)} – 7.20\). The ‘p’ value of this line is 0.452, which tells us that this line is not significant. I had decided to call a regression line significant when the ‘p’ value, which STATA v.10 creates, is less than 0.05.
To conclude something more from these 11 projects, I needed to investigate the behavior of each component of the independent variable such as Incentives, Set Based Design, Process improvement and Last Planner™.

(b) Performance vs. Incentives

The regression line between incentives and performance is \( Y \) (performance) = \(0.8890 \times X\) (incentives)+1.0877. The p value of this line is 0.59, which is not significant. The scatter plot in Figure 5-20 shows a complicated pattern.

Figure 5-20: Regression line between performance and incentives in the first phase
(c) Performance vs. Set Based Design

The regression line between Set Based Design and performance is \( Y \) (performance) = -0.1676\( \times \)X (set-based design)+9.0962. The \( p \) value of this line is 0.944, which is not significant. The scatter plot in Figure 5-21 shows a complicated pattern.

![Figure 5-21: Regression line between performance and Set Based Design in the first phase](image)

(d) Performance vs. Last Planner\(^{TM}\)

The regression line between Last Planner\(^{TM}\) (LP) and performance is \( Y \) (performance) =1.7797\( \times \)X (LP)-6.5758 in Figure 5-22. The \( p \) value of this line is 0.43, which is not significant.

![Figure 5-22: Regression line between performance and Last Planner\(^{TM}\) in the first phase](image)
5.2.3.3 Result from the eleven projects with a restructured scoring

Considering the result in the above, I came to have a question, “Is there any problem in scoring? Didn’t I put more importance on less significant factors in measuring Lean Construction?” If we had enough cases, a normal linear scoring methodology would have produced a similar result. However, the total number of cases was 58 until the end of the second phase (remember that this phase is the first phase). This small sample could be influenced by the weight of the score of each indicator.

To find out more effective data scoring, I discussed with Dr. Glenn Ballard, who had participated in creating Last Planner™. After the discussion, I categorized the thirteen items of Last Planner™ in Table 5-1 into a new five indicators. The five indicators are:

(a) Removing the reasons of weekly work plans’ failures.
(b) Checking the success rate of the weekly work plan.
(c) Pulling mechanism delivering handoffs instantly on the demands of the next workers.
(d) Checking readiness of a work before locating it in a weekly work plan.
(e) Relevant specialty contractors’ participation in scheduling.

Table 5-2 describes the detailed categorization of the thirteen items of Last Planner™ in Table 5-1 to the five indicators. The answer to each question asking about individual item in Table 5-1 took 1 as the perfect score so that if a project gets the perfect scores from all questions, its total score of Last Planner™ Implementation (LPI) is 13. However, the new version’s perfect score of a project is 5.

<table>
<thead>
<tr>
<th>Five big categories</th>
<th>The thirteen items in Table 5-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal of the causes of Weekly Work Plans (WWP)’ failures</td>
<td>% of causes of weekly work plans’ failures, being removed before executions of similar plans.</td>
</tr>
<tr>
<td>Check of the success rate of WWPs</td>
<td>% of Specialty Contractors (SCs)’ investigating whether the causes of similar weekly work plans have been removed before their works’ executions.</td>
</tr>
<tr>
<td>Pulling in delivering handoffs</td>
<td>% of SCs investigating the next worker’s readiness. % of processes having communication tools with adjacent ones. % of handoffs defined before their entering a phase. Correcting the master schedule by a phase schedule about the wrong decision made in the master schedule. Number of aspects considered in constraint analysis. Timing of constraint analysis. % of SCs doing constraint analysis. % of SCs doing a first run study. Correcting a phase schedule by a constraint analysis about the wrong decision made in the phase schedule. Correcting the wrong decision made in a constraint analysis during a weekly work planning.</td>
</tr>
<tr>
<td>Check of a work’s readiness before located in a WWP</td>
<td></td>
</tr>
<tr>
<td>Specialty contractors’ participation in Scheduling</td>
<td>% of SCs participating in a phase schedule.</td>
</tr>
</tbody>
</table>
Figure 5-23 is the result of the restructured scoring of LPI. The regression line between $Y$ (performance: sum of the cost reduction and the schedule reduction) and $X$ (LPI) is $Y=8.752 \times X - 20.279$. The p value is 0.046, which is significant statistically. The R-squared value, representing the fraction of $Y$’s variation that is explained by $X$’s variation based on the regression line, is 0.3740. The adjusted R-squared value, considering degree of freedom, is 0.3044. If $Y$ is less than zero, the sum of cost overrun (%) and schedule overrun (%) is bigger than zero. In short, it meant that the project delayed or spent more money than planned to a certain degree.

There seems to be an outlier in Figure 5-23 but I didn’t delete it because one of the purposes of this research was to find out the causes of the outliers through case study as section 5.3 described. The result of Figure 5-23 based on the restructured measurement really encouraged me to continue the research hypothesis testing further.

![Figure 5-23: Regression line between performance and Last Planner™ based on Table 5-2](image)

5.2.3.4 Findings from the eleven projects

First of all, the survey structure requesting many respondents for only one project could harm the response rate. The fact that this research gathered only eleven projects during one year (Oct. 2009 to Oct. 2010) showed that the data collection strategy demanding several respondents for a project had not been appropriate in terms of a response rate. Thus, I decided to restrict the respondents of a project to the general contractor of the project.

Second, asking too many questions of respondents likely also limited the response rate. Thus, I decided to reduce the questions having been used in this phase based on Table 5-2 for the second phase so that the respondents were requested to answer only the core questions about Lean Construction. Table 5-2 only deals with Last Planner™.
The other concepts, such as incentives, Set Based Design, and process Improvement through Value Stream Analysis, were also reduced. Table 5-3 is the result of reduction. These reduced questions were used in the second phase’s survey.

Table 5-3: Scoring structure in the second phase

<table>
<thead>
<tr>
<th>Systemized Concepts</th>
<th>The questions in the first phase</th>
<th>The questions in the second/third phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) General Contractor (GC)’s investigation of the best practices before calculation of the expected cost of the project: Yes/No.</td>
<td></td>
<td>Not Available (NA).</td>
</tr>
<tr>
<td>(2) GC’s participation in feasibility study: Yes/No.</td>
<td>(1) Same as the left.</td>
<td></td>
</tr>
<tr>
<td>(3) % of Specialty Contractor (SC)s participating in feasibility study: Percentage.</td>
<td>(2) Specifying all SCs participating in the feasibility study: If Mechanical (M), Electrical (E) and Plumber (P) SC participated, the score is 0.75 (0.25 per one of M, E, or P SC). If there are additional SCs after including M, E and P, it will be given 0.25 more. Other cases in measured by subjective criteria.</td>
<td></td>
</tr>
<tr>
<td>(4) Existence of Target Cost (duration) less than the expected cost (duration): Yes/No.</td>
<td>NA.</td>
<td></td>
</tr>
<tr>
<td>(5) GC’s participating in setting Target Cost (duration): Yes/No.</td>
<td>NA.</td>
<td></td>
</tr>
<tr>
<td>(6) % of SCs participating in setting Target Cost (duration): Percentage.</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>(7) Existence of incentives in cost reduction: Yes/No.</td>
<td>(3) Specifying All positive and negative incentives; if there are equal to or more than three incentives (cost, time, and other), the score is 1, if two incentives, the score is 2/3, if one, 1/3 and if none, 0.2.</td>
<td></td>
</tr>
<tr>
<td>(8) Existence of incentives in time reduction: Yes/No.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(9) Existence of incentives in other performance improvements: Yes/No.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(10) GC’s participating in setting incentives: Yes/No.</td>
<td>NA.</td>
<td></td>
</tr>
<tr>
<td>(11) % of SCs participating in setting incentives: Percentage.</td>
<td>NA.</td>
<td></td>
</tr>
<tr>
<td>(12) Performance assessment after completion: Yes/No.</td>
<td>NA.</td>
<td></td>
</tr>
<tr>
<td>Set Based Design</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(13) Performance assessment open to the market: Yes/No.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(14) Using Open account: Frequency.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Start of GC’s participation in a project: there are 5 steps.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business planning gets 1, Feasibility study gets 4/5, Beginning of general</td>
<td></td>
<td></td>
</tr>
<tr>
<td>design gets 3/5, During design gets 2/5, and After design gets 1/5.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) Start of SCs’ participation in a project: same to the right above.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) % of SCs participating in design; Percentage.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4) Whether GC decomposed the target cost into components of a project; Yes/No.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5) % of SCs participating in the decomposition of the target cost; Yes/No.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(6) Designers’ consulting other engineers; Frequency.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(7) Designers’ consulting GC; Frequency.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(8) Designers’ consulting SCs; Frequency.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(9) Review of design alternatives as many as possible; Frequency.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(10) Narrowing down design alternatives based on constraint analysis; Frequency.</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Value Stream Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Concurrent design of product and process; Frequency.</td>
</tr>
<tr>
<td>(2) % of SCs participating in process design; Percentage.</td>
</tr>
<tr>
<td>(3) Minimizing batch size of material while process design; Frequency.</td>
</tr>
<tr>
<td>(4) Standardization of material/process/or component while process design;</td>
</tr>
<tr>
<td>Frequency.</td>
</tr>
<tr>
<td>(5) Inventory management while process design; Frequency.</td>
</tr>
</tbody>
</table>

(1) Specifying all SCs participating in design: See the (2) in incentives of the second phase.

(2) Designers’ consulting GC/SCs: Frequency.

(2) Examples of Process improvement: if there is any one, the score will get 1 and if none, 0.

102
5.3 The second phase of data collection

5.3.1 How to find member of the Lean Construction Projects

The appropriate sample of this phase is a purposive sample including the members of the sample of the first phase. Instead of attending relevant conferences, which was used in the first phase to collect members of the sample, I used the e-mail list of the IGLC group in Yahoo\textsuperscript{45} for this phase’s additional members in the sample.

Because the main purpose of this phase was to modify the form or the measurement methodology thorough case studies, this phase intentionally included some Korean projects. To be consistent with the meaning of the purposive sampling, this research chose Korean construction projects selectively among those that were known to have implemented the similar concepts to Lean Construction, such as contractors’ participation in design or scheduling.

It was not so difficult to find the Korean projects having used the principle of collaboration among construction parties. The Ministry of Construction and Transportation of South Korea had started an innovative movement to encourage the collaboration among construction participants for mutual success (MOCT, 2007-c). As a result of this movement, several public projects enforced the collaborations between the owners and the contractors and I succeeded in contacting them.

5.3.2 Structure of scoring the second phase projects

Basically, the survey in the second phase measured the same concepts as the survey of the first phase did but the questions were modified from those of the first phase for easier collecting as the findings from the first phase in 5.2.3.3 already illustrated.

As for Last Planner\textsuperscript{TM} Implementation (LPI), the second phase’s survey employed the five questions described in Table 5-2. As for the other concepts, such as Set Based Design, process improvement, and incentive, Table 5-3 shows how the second phase’s survey transformed the first phase survey’s questions.

Many questions having been used in the first phase were deleted, as Table 5-3 shows, if they were considered to be important enough. For example, many aspects of Value Stream Analysis, such as ‘minimizing the batch size of materials,’ ‘standardization of materials/process,’ ‘inventory management’ and ‘preassembly of materials,’ were deleted since a process improvement could take on many other forms, which could not be limited into the forms described as Values Stream Analysis in the first phase.

\textsuperscript{45} http://finance.dirgroups.hayoo.com/group/iglc/message/677
The questions asking relatively new techniques, such as target costing, were also deleted because many respondents would not be able to answer correctly due to lack of understanding even though the respondents were believed to be familiar with Lean Construction.

5.3.3 Result of the survey in the second phase

Total 58 projects participated in this phase’s survey. With the new sample I again regressed Y (the performance indicator, sum of the cost reduction and the schedule reduction of a project) on X (the degree of implementation of Lean Construction, comprised of Incentive, Set Based Design, Process improvement through Value Stream Analysis, and Last Planner™, of the project) yielding the result shown in Figure 5-25. The regression line is $Y = 3.41X - 25.92$. The $p$ value of this model’s slope is 0.021, which is significant (less than 0.05). The R-squared value, which represents the portion of Y’s variation that can be explained by X’s variation based on the regression model, is 0.092 and the Adjusted R-squared value considering the degree of freedom in addition to the R squared is 0.076.

I should say that the performance indicator used in the Korean projects was slightly different from that used in other countries’ projects. The performance indicator in other countries was $[(\text{the approved budget-the actual cost})/\text{the actual cost} + (\text{the approved schedule-the actual schedule})/\text{the actual schedule}] \times 100$. However, as for the Korean projects, it was $[(\text{A cost estimated as the approved budget-the actual cost})/\text{the actual cost} + (\text{A schedule estimated as the approved schedule-the actual schedule})/\text{the actual schedule}] \times 100$. When I asked the Korean contractors to provide this performance indicator, all of them gave me Zero as the indicator. At first, I believed that the general contractors intentionally hid the approved budget. Probably, the costs that the Korean contractors provided through the survey were the actual costs of their projects but they were reluctant to tell the approved budgets. I needed to find the approved budgets in other ways.

To solve this problem, I investigated the web site, KISCON, used in producing the Korean random sample, which contains the contractual costs and durations of most of the Korean projects (Ch. 4.5). According to the 22nd provision of the Framework Act on the Construction Industry and to the 26th provision of the Enforcement Decree of the Act, every contractor should report some information such as contractual cost or duration to the owner through this web site within a certain period of time after the contract.

With the help of the government agency, I came to find the contractual cost/duration that had been reported by the contractors through the government system. These cost/durations were probably bigger than the initial contractual costs/durations because they were made a certain period after the contract but they were agreed between the owners and the contractors to be reported to the government system. Thus, I regarded them that were provided by the web site as the approved budgets/schedules.

However, after data analysis and interview, I found the concept, ‘approved budget’ had not been appropriate in describing the Korean Construction Industry from the beginning because all projects had used a lump-sum price contract without a incentivizing fee or a reimbursable cost in which a cost reduction from the approved budget had not been necessary. Usually, a contractor’s profit is not revealed to owner, which might mean that a bigger lump-sum contractual cost leads to a bigger profit of the contractor. It would have been a stupid thing for a Korean contractor to have reduced his/her approved budget.
Under this aforementioned condition, most of the Korean contractors tend to induce change orders to increase the total contractual costs. In fact, all Korean projects underwent cost overruns, which we can see in Table 6-2. According to Table 6-2, the Design Build and Alternate Design Bid projects’ average cost overrun percentage compared to the initial contractual costs was 7.592 and its 95% of the confidence interval was from 4.552 to 10.632 (%), which means 95% of the projects underwent at least 4.552% of a cost overrun.

As for the Design Bid Build projects, the mean of cost overrun was 11.705% and the 95% of the confidence interval was from 6.798 to 16.613 (%), which also means 95% of the projects underwent at least 6.798% of a cost overrun.

In conclusion, I decided to replace ‘approved budget’ with ‘initial contractual cost’ in Korean project’s performance indicator. This was also addressed in section 5.3.4.7 Findings from case studies in more detail. This replaced contractual cost was used in the fourth phase’s survey on the randomized Korean sample.

The points named case 1 to 6 in Figure 5-24 were chosen for the case studies having been described in Figure 4-6 (model testing or model building case study). The detailed strategy and rationale of the selection were explained section 5.3.4.

![Figure 5-24: Regression line between performance and Lean Construction in the second phase](image)

Figure 5-24: Regression line between performance and Lean Construction in the second phase

105
Table 5-4: The basic statistics of Figure 5-24

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>Number of object = 58</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>2370.64</td>
<td>1</td>
<td>2370.64</td>
<td>F(1, 56) = 5.66</td>
</tr>
<tr>
<td>Residual</td>
<td>23467.26</td>
<td>56</td>
<td>419.06</td>
<td>Probability &gt; F = 0.021</td>
</tr>
<tr>
<td>Total</td>
<td>25837.91</td>
<td>57</td>
<td>453.30</td>
<td>R-squared = 0.092</td>
</tr>
</tbody>
</table>

Adjusted R-squared = 0.076

Root Mean Square Error = 20.47

| Coefficient | Std Errors | T     | P>|t| | 95% confidence Interval |
|-------------|------------|-------|------|-------------------------|
| X in Figure2 | 3.41       | 1.43  | 2.38 | 0.021                   | .54       | 6.28     |
| Constant    | -25.92     | 9.22  | -2.82| 0.007                   | -44.41    | -7.44    |
5.3.4 Case study in the second phase

5.3.4.1 Case selection strategy

Before addressing the rationale of the case selection, I should say an important assumption used in the second phase that the independent variable, the degree of Lean Construction (LC), already reflects the variation caused by the nationality in nature. This is because all countries should have common structures in managing their construction industries and LC in my survey was designed to measure the structures’ relative importance being taken account of in the overall processes.

In more detail, every construction project can be addressed by its commercial terms, the degree of integration in organizing the project, and the management philosophy (Thomsen et al., 2009). In my survey, incentives measures LC in the commercial terms, incentives and Set Based Design (SBD) measure LC in the integration of the organization, Value Stream Analysis (VSA) and Last Planner™ (LP) measure LC in the management philosophy. Different nationality can cause different score in each sub-concept but nationality cannot address anything beyond the three structures that Thomsen et al. (2009) pointed out. This is one of the important assumptions used in the second phase. To confirm this assumption, I did several t-tests comparing performance indicator and Lean Construction between the Korean projects and the other nations’ ones collected for this phase.

Because the Bartlett’s test for equal variance of performance indicator between the two groups (Korean vs. otherwise) showed the p value, 0.488, I used a two sample T-test with equal variance (a normal t-test) to compare performance indicator between the two groups. The 25 Korean projects among the total 58 projects in the sample showed -11.10 as the average performance indicator while the other 34 projects’ mean in performance was -0.24. The t value of mean difference was 2.00 and the p value was 0.05, which was at the border between significance and insignificance. However, I decided to see it as a significant difference.

Anyway, Korean projects’ performance was not better than that of the others, which showed that whether a project was a Korean one might be an important causal factor influencing performance indicator. The next investigation was to see if the variation of performance caused by whether a project is a Korean one was coincident with the variation caused by LC. Figure 5-24 showed that LC was proportionate to performance. I thought that because most of the Korean projects showed worse performance, if most of them also showed lower degree of LC, then, whether a project was a Korean project was proportionate or correlated to LC in predicting performance. In this case, we can say that a nationality determines LC and the LC addressed by the nationality determines the performance consecutively.

As for the comparison of LC between the two groups, the Bartlett’s test showed the p value, 0.048 (it violated the equal variance condition within a group for a normal T test), so that I did an Unequal Welch T test instead of a two-sample T test to compare LC between the two groups. The Korean projects’ mean value of LC was 4.80 and the other projects’ mean of LC was 7.19. The t value of the difference was 6.43 and the p value was 0.000. Definitely, there was a significantly big difference of LC between the two groups.

Judging from the aforementioned two T tests, Korean projects seemed to have worse performance indicators and have employed lower degree of Lean Construction. This symptom was coincident with the result shown in Figure 5-24. That is to say, if projects with a same
nationality show homogeneous feature in LC and the predictable appearance in the performance indicator based on the regression model in Figure 5-24, we can say nationality can be a causal factor determining LC, which consecutively determines the performance predicted by the regression model in Figure 5-24.

The following separate regressions of performance on LC in each group (Korean vs. otherwise) showed that there was no conspicuous sub-variable of LC influencing performance in the context of the Korean industry. The regression line of performance on LC in the Korean projects was \( Y=0.13\times X-11.71 \) with the p value, 0.975 and the regression line in the other nations’ projects was \( Y=3.53\times X-25.60 \) with the p value, 0.087. In interpreting this result, we should focus especially on the Korean group because the other group contained several nationalities (the USA, Norway, Nigeria, Saudi Arabia and Spain), which already violated homogeneity in the group. Definitely, there was no correlation between LC and performance indicator in the Korean group, which meant the rest of the components of LC, excluding nationality, lost their significance in predicting performance. Thus, I concluded that a nationality would determine the meaningful parts of LC in terms of predicting performance.

Based on the aforementioned argument, I decided to leave the regression line in Figure 5-24 as it was without separating nationality as another independent variable from LC. The following is the detailed rationale of selecting cases based on the regression line in Figure 5-24.

Even though the regression line in Figure 5-24 shows significance, the scattered plots around the line to a degree urged me to investigate what happened the plots far from the line. Thus, I did both the model testing case studies that are necessary when the regression model shows a robust result and the model building case studies that are necessary when the regression model needs to be modified for a better fit. I selected the cases according to the strategy described in Figure 4-2 and Table 4-1. The result of the selection is represented in Figure 5-24. The following is the rationale of each case’s selection.

The observed independent variable of the first case (the case 1 in Figure 5-24) was 5.59 and the observed dependent variable was 22.73. According to the regression model in Figure 5-24, the predicted dependent variable was \( 3.41\times 5.59-25.93=-6.89 \). The distance of the observed dependent variable from the predicted variable was 29.58, which was bigger than the Root Mean Square errors (RMS) in Table 5-4, 20.42. The location of this case against the regression model was similar to that of point, ‘A’ in Figure 4-2 that is represented as an MSDO case selection in Table 4-1. Thus, it was used for a model building case study. For information, this was a Korean project.

The observed independent variable of the second case (the case 2 in Figure 5-24) was 6.84 and the observed dependent variable was -22.90. Based on the regression model in Figure 5-24, the predicted dependent variable was -2.61. The distance of the observed dependent variable from the predicted dependent variable was -20.29, of which the absolute value was also bigger than the RMS in Table 5-4. The location of this case against the regression model was similar to that of the point, ‘C’ in Figure 4-2 that is represented as a ‘MSDO’ case selection in Table 4-1. Thus, it was used for a model building case study. For information, this was a Korean project.
The observed independent variable of the third case (the case 3 in Figure 5-24) was 5.50 and the dependent variable was -8.61. The predicted dependent variable based on the regression model was -6.98. The difference of the observed dependent variable from the predicted variable was -1.62. Contrary to the first and the second case, the position of this case was near the regression model. The location of this case against the regression model was similar to those of B, D or F in Figure 4-2 that was represented as an MSSO selection in Table 4-1. Thus, this was used for a model testing case study. This was also a Korean project.

The observed independent variable of the fourth case (the case 4 in Figure 5-24) was 7.9787 and the dependent variable was 0.8622. The predicted dependent variable by the model was 1.284. The distance of the observed dependent variable from the predicted dependent variable was -0.4218. Similar to the third case, this case was consistent with the regression model. This case was used in a model testing case study. This was not Korean project but it was known as an Integrated Project Delivery (IPD) project. An IPD project emphasizes on collaboration in making important decisions such as ‘setting target contractual cost,’ ‘setting pain/gain sharing system’ and ‘making design or scheduling’ (Thomsen et al., 2009). Thus, IPD projects seem to have employed many concepts used in ‘Lean Construction’ even though I was not sure if IPDs have employed production management technology such as Last Planner™. Thus, this case was used as a model testing case, which showed us how processes in Lean Construction played roles in the project.

The observed independent variable of the fifth case (the case 5 in Figure 5-24) was 4.6762 and the dependent variable was -103.07. The predicted dependent variable was -9.9772 based on the regression model. The distance of the observed dependent variable from the predicted dependent variable was -93.0928, of which absolute value was far bigger than the two standard errors (20.471, Root MSE in Table 5-4). Lieberman (2005) recommended including the case whose deviation is more than the two standard errors as one for a model building case study. The example is H in Figure 4-2. Thus, this was a good specimen for a model building case. This was not a Korean Project and was collected through a Lean Construction-related e-mailing list.

The observed independent variable of the sixth case (the case 6 in Figure 5-24) was 4.9241 and the observed dependent variable was 29.1523. The predicted dependent variable based on the regression model in Figure 5-24 was -9.1318. The distance of the observed dependent variable from the predicted variable was 38.2841, which is nearly two times bigger than the Root MSE, 20.471 in Table 5-4. This is a Korean Project and this shows a similar behavior to the first case but with a bigger degree. This case played a role as a counterpart to the fifth case.
5.3.4.2 The first case

Table 5-5 shows the synopsis of the first case.

| Brief explanation or remarkable things | 1. Design-Bid-Build (DBB) 2. Reduction in 50% in design duration. | 1. 75-100% of the handoffs of a phase were defined before the phase. 2. 75-100% of all specialty contractors participated in phase scheduling. 3. A wrong decision made in the master schedule could be modified in a phase schedule: Often. 4. Considered constraint: prerequisite works, contractual approval, sequence, resource, duration, funding, natural condition and labor/equipment. 5. Timing of constraint analysis: from 1 to 6 weeks before execution. 6. 50-75% of all specialty contractors did constraint analysis. 7. 75-100% of all specialty contractors did a first run study. 8. A wrong decision made in a phase schedule could be modified in a constraint analysis: Often. 9. 75-100% of all specialty contractors investigated the next workers’ readiness. 10. 50-75% of all works had instant communication channels with the adjacent works. 11. A wrong decision made in a constraint analysis of a work could be modified right before being located in the weekly work plan. 12. 75-100% of all causes of the weekly plans’ failures were cured. 13. Specialty contractors investigated if the causes of weekly plan failures were removed: Often. |
| Production control in design | 1. 50-75% of the engineers participated in scheduling for design. | Production control in design (Last Planner™) |
| Point Based Design | 1. Each designer did his/her own job only after the previous designers had finished their jobs: Often. | |
| Process improvement in construction | 1. 50-75% of the specialty participated in process design. 2. Minimization of batch size of material: Often. 3. Standardization of material/process/document: Often. 4. Management of material’s inventory: Often. 5. Preassembly of materials: Often | |
| Incentives | 1. None in design. 2. None in construction. | |
This project is a public project. Table 5-5 shows some unique features of the first Case. This project used Set Based Design (SBD) strategy in design in part. Even though there was not contractors’ participation in design because this is a DBB project, the designers always reviewed and narrowed down the design alternatives based on constraint analysis with consulting each other.

However, they often used Point Based Design (PBD) strategy as described in Table 5-5, which is the opposite concept of SBD. I started thinking that there could be a gap between their understanding and what Lean Construction says about SBD. If the architect got high score in SBD, he/she should record relatively low score in PBD. If a designer is allowed to review design alternatives only after the previous designers finished their works, how could all the relevant specialists collaborate in reviewing and narrowing down the design alternatives at the same time?

I tried to answer why this discrepancy was present. One answer could be that the survey was not appropriate in measuring SBD, or that because a respondent could not understand the survey or Lean Construction, he/she could not answer correctly. To find out more probable cause, I reviewed the questions about SBD again. The following was the real sentence used in the questions.

< Question about the SBD >
Did you and each specific engineer, who participated in the product design of the project, consult other related specific engineers while designing its own part?

[Korean version of the immediate above]
이 공사의 상품설계에 참여한 귀하와 각 전문 설계 기술자들은 각 맡은 분야를 설계할 때 관련된 다른 전문가 (specialist) 들의 의견을 들었습니까? 가장 가까운 답을 고르세요.

<Question about the PBD>
Were you and each specific engineer, who participated in the product design of the project, involved in making the product design only after the previous specific engineers finished their works?

[Korean version of the immediate above]
이 공사의 상품 설계를 담당한 귀하와 각 전문 설계 기술자들은 담당한 부분의 상품 설계를 할 때 순서적으로 앞의 전문 기술자 (specific engineer) 들이 각자의 부분을 끝낸 이후에야 설계과정에 참여 하였습니까? 가장 가까운 답을 고르세요.

First, I found that there was inconsistency in describing ‘specific engineer’ between the Korean versions’ question asking about SBD and the question about PBD. The Korean question asking SBD translated ‘specific engineer’ to ‘specialist.’ This difference could cause different interpretation. Thus, I decided to change the ‘specialist’ in the question asking SBD to the ‘specific engineers’ for consistency for the fourth phase, which was discussed in section 5.5.
Table 5-5 shows that this project tried to improve its construction processes by using minimized batch sizes, inventory management, preassembly and standardization. All these four features are known as the techniques of Value Stream Analysis as Table 3-16 introduced in section 3.2.3. In addition, to judge if a respondent answered the question with proper caution, I decided to include an ‘essay type’ question asking to describe real examples of process improvement in the fourth phase’s survey, the next survey on Korean projects.

Sometimes, Table 5-5 shows that the respondent felt confusion in answering some similar questions. For example, the respondent answered that 75% to 100% of all specialty contractors did a first run study and 50% to 75% of them did constraint analyses. A first run study is an experimental execution of a work before the actual execution of the work to see if there is any constraint left that could disturb the execution of the work as defined in Table 3-19. Logically, because a first run study is a kind of constraint analysis, the percentage of the specialty contractors doing a first run study should be less than or equal to that of the specialty contractors doing constraint analysis. I reviewed the questions again and concluded that there were few unclear things in interpreting questions but the respondent seemed to be confused about those questions. Asking too many questions might be the cause anyway. The detailed questions about constraint analysis and a first run study is described in the A.3

According to Table 5-5, this project frequently corrected an old schedule of a work, which was found not to be appropriate when the relevant workers scheduled the work in more detail. To verify this, I investigated a relevant article, of which identity is not be revealed in this research to protect the privacy of this project, so that I found an interesting fact as follows. In fact, the relevant article was a government report that explained the achievements of an innovative movement driven by a relevant public sector to make the collaborative mood among construction parties more prevalent in the industry.

The main contractor gave the money needed for the changes to the sub contractors before the official approval of the changes by using the money it had received as pre-investment before construction to relieve the sub contractors’ financial burden

The owner gave the money needed for the changes in rough estimate to the main contractor before the official approval of the changes to relieve the main contractors’ financial burden

The upper quotations addressed a proactive funding as a part of the change orders. A proactive funding, to correct the mistake that had been made in a previous design/schedule, before an approval of the official change order was a good example of modifying the old decision based on the current constraint analysis. My next question was whether this proactive funding is usual in Korean public projects. If this is a usual thing, their production control might not be regarded as extraordinarily better one. For this, I investigated Chapter 9 of the public accounting directives, which is numbered as # 2200.04-159-15 and named as ‘Criteria of Execution of Contracts related to Government Bidding.’ According to the regulation, a proactive funding is possible but it must be accompanied by the owner’s special representatives’ periodic inspections of whether it was used in correct way.

Even though the regulation mentioned above allowed the owner to give the contractor proactive funds, this activity requested the owner’s subsequent responsibility of inspections, which meant the owner’s extra efforts for better performance. Their proactive funding could be regarded as the owner’s extra collaboration for the project performance in favor of the contractors.
In addition, the article quoted above said the owner’s representative had the contractors start relevant construction before the official approval of the change orders. Of course, another public accounting directives, #2200.04-104-22, allows this activity but this activity is not mandatory. I came to conclude that the owner’s attitude toward project performance or collaborative outcome was extraordinary.

Table 5-5 was made of the answers from the relevant participants of this project to additional questions beyond the survey questions used in Figure 5-24. Even though there was any incentive neither in design nor in construction in Table 5-5, the article quoted above said that the general contractor incentivized the specialty contractors by giving the chance of the private contracts in future instead of that given by a competitive bidding if the specialty contractors showed excellent performance. In addition, even though the general contractor used a competitive bidding based on the least price in the procurement of the specialty contractors, the general contractor investigated if the submitted bid prices were too low prices lest the winner should suffer from the too low construction cost. The general contractor was believed to have used incentives and non-cost based procurement in order to induce better performance from the specialty contractors.

As for process improvement, the article quoted above showed some examples as follows.

> They used truss beams to reduce the number of the supporting posts, and horizontal steel bars fixing steel rebar in order to enhance the concrete performance and reduce construction waste such as wooden form for concrete curing.

> They used different colors per different work to increase of efficiency and safety of construction by more visual control.

> They used a computerized bidding system for the procurement of subcontractors.

Judging from the examples in the above, their good appearance about the process improvement described in Table 5-5 was reaffirmed.

The article also addressed several collaborative meetings among construction parties including the owner, the general contractor and the specialty contractors. The participants held big conferences at the points of the important milestones and held monthly and weekly meetings in order to solve the current problems and to prevent the future problems. More interestingly, they used a common office for instant communicative collaboration among relevant contractors, whose concept is very similar to the ‘Big room,’ which was declared as the desirable characteristics of an Integrated Project Delivery Project in Cohen et al. (2010). The ‘Big Room’ means Co-location of teams (Cohen et al., 2010). In addition, even though they were not familiar with the concept, ‘quality criteria’, with which every specialist investigates the readiness of his/her works finally before executing them in Last Planner™, the article recorded that they used their own quality criteria during the construction.

Most of the features recorded in Table 5-5 were supported by the additional investigation so that I concluded that this project improved process by innovative methodologies and controlled the construction processes successfully with collaboration. To trace better the processes of this project based on Lean Construction, I did additional phone interviews with the respondents. This interview was done on Oct. 25 2010 (the interview for the first case on Oct. 25, 2010: A.4)

As result of the phone interview, I found that the contractor used the production control based on plan reliability and it was effective in this project. According to the production control principle, they managed schedules.
Previously made schedules were frequently modified based on the current constraint analysis, which considered every possible cause harming the plan reliability. However, the Set Based Design used by the architect was proven not to be an appropriate one as Lean Construction indicates because of the relevant Korean regulation that orders the owner to separate the contracts between an electrical/communication design and the others. Actually, their method in designing was nearer to Point Based Design.

In terms of process tracing, this project shows how Lean Construction worked through the processes. The survey respondents, especially the general contractor, understood the question well. However, even considering high implementation of Lean Construction, definitely this project showed too good performance beyond the prediction of the regression model in Figure 5-24.

It did not take long time for me to find the actual cause of this symptom. The cause was my mistake in the data input. Unlike to other projects, I included the reduction of the design period into the total project performance by mistake. As mentioned before, the performance in design had been decided not to be included in calculating the project performance (Ch. 5.1.2). In addition, the architect was not sure if there had been such a big reduction in the duration of the design and he mildly denied that reduction by saying that it was really rare thing to reduce the contractual duration of a general design in the phone interview (A.3). Thus, after correcting this mistake, this case came to be much nearer to the regression line. At this point, the corrected dependent variable of this project was changed from 22.7273 to -6.9215.

Another interesting thing I found was that the contractor did not know anything about the contractual cost/duration collected from KISCON, the government-operating web site that was introduced in section 5.3.3. This made me question the validity of the government information.
### 5.3.4.3 The second case

Table 5-6 shows the brief explanation of the second case

#### Table 5-6: Main characteristics of the second case collected by additional questions

| Brief explanation or remarkable things | 1. Alternate Design-Bid  
2. Cost growth 22.89% for 70 months. Not completed yet.  
3. The completion date was delayed by years not months. | 1. 50% to 75% of all handoffs of a phase were defined before the phase.  
2. 25% to 50% of all SCs participated in a phase scheduling.  
3. A wrong decision made in the master schedule could be modified in a phase schedule: Sometimes.  
4. Considered constraints: 50% compared to the first case  
5. Timing of constraint analysis: Before 1 to 6 weeks before execution.  
6. 25% to 50% of all SCs did constraint analysis.  
7. 50% to 75% of all SCs did a first run study.  
8. A wrong decision made in a phase schedule could be modified in a constraint analysis: Sometimes.  
9. 25% to 50% of all SCs investigated the next workers’ readiness.  
10. 75% to 100% of all works had instant communication channels with the adjacent works.  
11. A wrong decision made in the constraint analysis of a work could be modified right before the work’s being located in the weekly work plan: Often.  
12. The causes of the weekly plans’ failures were cured: Often  
13. SCs investigated if the causes of weekly plan failures were cured: Often |
| Set Based Design | 1. The General Contractor (GC) participated in the beginning of the design.  
2. GC did not investigate the best practices before design. The architect did it.  
3. GC did not participate in setting contractual cost.  
4. Decomposition of total cost into project components before design: No.  
5. Designers’ consulting GC: Always.  
4. Consulting other specific engineers: Sometimes.  
5. Reviewing design alternatives: often  
6. Narrowing down design alternatives based on constraint analysis: sometimes | Production control in construction (Last Planner™) |
| Point Based Design | 1. Each designer did his/her own job only after the previous designers had finished their jobs: sometimes. |
2. 0% to 25% of the specialty participated in process design.  
3. Minimization of batch size of material: Sometimes.  
5. Management of material’s inventory: Sometimes.  
| Incentives | 1. None in design  
2. None in construction |
This case shows much worse performance than the predicted one by the regression line in Figure 5-25. Because the General Contractor (GC) of this project made the design\textsuperscript{46}, this project got more scores than the first case, a DBB project, in view of contractors’ participation in design. Even though this project was not completed at the time of survey, it recorded 22.89\% of cost overrun compared to the original budget and delayed by years not months. This case study was to find out what caused this project to go through cost overrun in spite of relatively high degree of Lean Construction implementation.

Apparently, the second case’s production control was not as good as that of the first case. Only 25 to 50\% of all Specialty Contractors (SC) participated in phase scheduling of the second case while 75 to 100\% of all specialty contractors did it in the first case. While the first case’s SCs investigated 8 factors in the constraint analysis including ‘prerequisite works,’ ‘contractual approval,’ ‘sequence,’ ‘resource,’ ‘duration,’ ‘funding,’ ‘natural condition’ and ‘labor/equipment,’ the second case’s SCs investigated only half of the 8 factors. Only 25 to 50\% of all SCs investigated the next workers’ readiness to receive their handoffs while 75 to 100\% of them did in the first case.

However, we cannot say the second case’s production control is worse than that of the first case only because of the factors described in Table 5-5 and Table 5-6. There could be other reasons. To find out them, I reviewed a relevant article in addition. To protect the identity of this project, I do not reveal the name of the article. According to the article, the second project operated organizational meetings periodically under the name of the Cooperative Organization for Mutual Success (COMS) every other month. The COMS meeting had several sub-meetings. All contractors should participate in a sub-meeting held every other week. The main purposes of COMS were:

(a) Maintaining transparent and balanced contractual relations.
(b) Discovering voluntarily the items needing cooperative solutions (education of workers, sharing technologies and supporting business administration).
(c) Trying to enhance product quality.
(d) Minimizing unnecessary disputes.
(e) Collaborating to define sequences of works.
(f) Increasing safety of working condition.

The COMS focused on integration and collaboration of all construction participants. In addition, the GC maintained the mentoring relation with the Specialty Contractors (SCs) in which the GC was the mentor and the SCs were the mentee. As for technical aspects in production control, the GC used a supporting program that had been developed by the GC. The project management program checked daily tasks’ progresses, managed daily supply chain of material and daily human/equipment management. Similar to the first case, the GC funded proactively the SCs before the official approvals of the change orders in the contracts between GC and SCs.

\textsuperscript{46} This project was an Alternate Design Bid project
So far, I could not find the real cause of the poorer performance of this project than that predicted by the regression model in Figure 5-24 except those shown in Table 5-6. Thus, I decided to do phone interviews with the respondents as I had done for the first case. The interview revealed the cause of the performance lied in the contractual type. According to the Act on Contracts to which the State is a Party, there are two different contract type about a public project whose duration is longer than a year. One is ‘long term continuous contract’ that guarantees only the total amount of cost of a project but not the annual budget plan of the project so that no body know when the project is completed. The other one is ‘continuous price contract’ that guarantees the total cost of a project as well as the annual budget plan. At the beginning, the second case took the long term continuous contract. The funding was unstable so that it was the main cause of the delay and the change orders. After a few years later, this project changed its contract to ‘continuous price contract.’

As a result of the interview, I found that the respondent was familiar with theory of Lean Construction such as the production control based on the plan reliability or Set Based Design strategy. The interviewee agreed that the theory of Lean Construction helped to enhance the project performance to a certain degree but he said the effect was limited. I agreed with his opinion to a certain degree because it will be very hard for the project to be managed based on constraint analysis if there is such a big restriction harming project reliability in contract as ‘a long term continuous project.’ Thus, I decided to insert a new question in the fourth phase survey on Korean projects asking whether a project employed the long term continuous contract.

The respondent did not know the existence of the price recorded in the government web site that was introduced in Ch. 5.3.3. I questioned again the validity of the contractual cost/duration provided by the government. The detail of the interview for the second case is in the A.5
### Table 5-7: Main characteristics of the third case collected by additional questions

<table>
<thead>
<tr>
<th><strong>Basic features</strong></th>
<th><strong>Process improvement in Design</strong></th>
</tr>
</thead>
</table>
| 1. Design-Bid-Build (DBB).  
2. Design and construction completion on time and on budget.  
3. No incentives in both construction and design. | 1. 50 to 75% of specific engineers participated in scheduling for the design.  
2. Minimization of material’s batch size in design: Sometimes.  
3. Standardization of materials and processes in design: Rarely.  
4. Materials’ inventory management in design: 25 to 50% |

<table>
<thead>
<tr>
<th><strong>Point Based Design</strong></th>
<th><strong>Process improvement in Construction</strong></th>
</tr>
</thead>
</table>
| 1. Designers’ starting their works only after the previous designers’ having finished their works: Often. | 1. 25 to 50% of Specialty Contractors (SCs) participated in scheduling for the process design.  
2. Minimization of material’s batch size in design: Sometimes.  
3. Standardization of materials and processes in design: Often.  
5. Preassembly of materials: Never. |

<table>
<thead>
<tr>
<th><strong>Set Based Design</strong></th>
<th><strong>Process improvement in Construction</strong></th>
</tr>
</thead>
</table>
2. Designers’ consulting other designers: Often.  
3. Architect’s reviewing the design alternatives as many as possible: Always.  
4. Architect’s narrowing down the design alternatives based on constraint analysis: Always. | 1. 25 to 50% of handoffs of a phase were defined before the phase.  
2. 50 to 75% of all SCs participated in phase scheduling.  
3. Correction of the wrong decision made in the master schedule by a phase schedule: Sometimes.  
4. Considered constraints: 62.5% of the first case.  
5. Timing of constraint analysis: 1 to 6 weeks before execution.  
6. 25 to 50% of all SCs did constraint analysis.  
7. Correction of a wrong decision made in a phase schedule by constraint analysis: Rarely. |

<table>
<thead>
<tr>
<th><strong>Production control in design</strong></th>
<th><strong>Production control in construction</strong></th>
</tr>
</thead>
</table>
| 1. 25 to 50% of handoffs of a phase were defined before the phase.  
2. Correction of the wrong decision made in the master schedule by a phase schedule: Never.  
3. Considered constraints: 62.5% of the first case.  
4. Timing of constraint analysis: Less than 1 week before execution.  
5. 50 to 75% of specific engineers did constraint analysis.  
6. Correction of a wrong decision made in a phase schedule by constraint analysis: Rarely.  
7. Specific engineer’s investigation of the next | 1. 75 to 100% of handoffs of a phase were defined before the phase.  
2. 50 to 75% of all SCs participated in phase scheduling.  
3. Correction of the wrong decision made in the master schedule by a phase schedule: Sometimes.  
4. Considered constraints: 62.5% of the first case.  
5. Timing of constraint analysis: 1 to 6 weeks before execution.  
6. 25 to 50% of all SCs did constraint analysis.  
7. Correction of a wrong decision made in a phase schedule by constraint analysis: Rarely. |
specialist’s readiness:
Sometimes.

8. Specific engineer’s having instant communication channel with adjacent ones: Often
9. Correction of a wrong decision made in a constraint analysis by a weekly work plan: Rarely.
10. Every specific engineer’s investigation if all causes of the past weekly plans’ failures were removed: Sometimes.

8. 25 to 50% of all SCs investigated the next workers readiness
9. 0 to 25% of all SCs had instant communication channel with adjacent ones.
10. Correction of a wrong decision made in a constraint analysis by a weekly work plan: Rarely.
11. Every specific engineer’s investigation if all causes of the past weekly plans’ failures were cured: Sometimes.
11. 25 to 50% of all causes of the weekly plans’ failures were cured.

This case was used as a model testing case study because it fits well the regression model in Figure 5-24 as mentioned in 5.3.4.1. The model testing study was done by an investigation of the relevant literature and additional interviews to see if the internal process of the project was coincident with the theory that had produced survey questions.

This DBB project’s production control was not better than that of the first project (DBB). 25 to 50% of all specialty contractors did constraint analysis in this project while 50-75% of them did in the first project. A wrong decision about a work having been made in a previous schedule was rarely corrected when the general contractor scheduled the work in more detail, while this kind of corrections often happened in the first project. Only 25 to 50% of all specialty contractors participated in the phase scheduling in this project while 50 to 75% of them did in the first case.

According to the relevant document that the provider gave me only under the condition of hiding the identity of the literature, this project also operated the Cooperative Organization for Mutual Success (COMS) as the second case did. Each party’s achievements in the COMS’ operation were assessed so that the relevant parties were awarded and were benchmarked based on the assessment. This assessment could be regarded as a non-contractual incentive even though there was no contractual incentive in the respondent’s answers. In addition to the COMS’ assessment, the general contractor gave the specialty contractors, who had shown the best performance, a right of participation in bid at earlier time and gave a waiver of the performance bond. This was also a non-contractual incentive. Definitely, they used incentives to enhance the project performance or to induce more collaboration from the specialty contractors.

The movement named as ‘self clean wave movement’ for preventing corruption was an additional interesting factor in their innovation. Judging from this movement, I thought that corruption among contractors was a relatively heavy problem in the nation’s industry, which also makes this nation’s industry unique in addressing performance. If corruption is dominant in the industry, measuring performance should be calibrated but this is beyond this research.

As the first case did, the general contractor gave the specialty contractors advanced payments up to 40% about the parts having been done before the contractual plan, which can be regarded as an effort to increase plan reliability.
According to Table 5-7, they ‘sometimes’ minimized the batch size of materials, ‘often’ standardized materials or processes and ‘often’ managed inventories of materials to reduce the waiting time of the materials.

I found in the article mentioned above that their efforts for process improvement achieved some substantial results such as reduction of concrete curing cycle time from five days to three days by changing the concrete admixture to the polycarbonate AE water reducer and preparation for the delay of rebar assembly in the raining season.

This project shows evenly distributed appearance in incentive, production control and process improvement. For a further trace of the processes, I did additional interviews with the survey respondents of this project. The detailed content of the interview is in the A.6.

The respondent understood well the meaning of each survey/additional question in Table 5-7. He knew well the production control theory, based on which the survey instrument had been made, but had an opinion that the production theory was kind of an ideal, which cannot be applied to the real world perfectly. For example, the third case was also a ‘long term continuous contract’ project in which there was big uncertainty in the funding plan similar to the second case. Thus, they pushed the project according to the plan having been made previously without serious consideration about funding, one of the most important constraints. If there was no money, the general contractor invested his/her own money and got paid back later by the owner. Another example in his saying about unreality of Lean production theory was the limit in operating an organization for cooperation among construction parties. The interview showed the owner, the general contractor and the specialty contractors operated an organization for cooperation similar to those of the first and the second cases. The organization achieved good but limited results. As for some suggestion relatively easy to be solved, such as constructing a staff lounge for summer work, the organization could provide a solution. However, if it was about a technical problem, the participants followed the traditional point based decision making process, in which the person, who had raised the problem, discussed the matter with the personnel right above him/her to make a formal report that was acceptable to the owner’s representative and contained several alternative solutions of the problem so that the owner’s representative finally decided if the report’s solution would be taken instead of participating in the production of the solution alternatives from the beginning.

If there is a clear line among the owner, the general contractor and the specialty contractors in hierarchical authority, collaboration is just an aim from the owner or higher party in the hierarchy for the lower subordinates. ‘Long term continuous contract’ or ‘Point Based Decision process’ are for the owner’s convenience and they helped only to enforce the hierarchical structure. Another good example of supporting the hierarchy is the Value Engineering (VE) in Korea. The hierarchical Korean society changed VE into another form of a change order as the A. 39 shows. When the owner felt a big load in his/her mind in doing an official change order, the contractor suggested VE to realize the change order as well as to relieve the owner’s mental burden. This trend is also found in a different interview about another project done on Apr. 26th 2009 (A.7)
The aforementioned additional literature review and interview showed that the third case’s processes were well explained by the basic principles that have produced the survey. The construction participants knew well the production theory but there were some actual restrictions to apply the theory to this project fully. In addition, the interviewee told me that if the survey had asked what percentage of the main specialty contractors participated in the phase scheduling the answer would have been ‘all’ instead of ‘25 to 50%’. Based on this, I changed ‘all the specialty contractors’ to ‘all the main specialty contractors’ in the relevant survey questions used for the fourth phase in section 5.5.

One thing, which I learned from this case, is that problems caused by contractual structure depended on the owner’s or the contractor’s will to overcome it. Both the second case and the third case used the same contract, ‘long term continuous contract.’ However, the third case’s owner tried to guarantee the annual budget plan while the owner of the second case could not. Of course, the general contractor in the third case tried to make work flow reliable even though there had been serious funding problems. Thus, I decided to regard the contractual problem as the owner’s degree of the constraint analysis instead of regarding it as one of strong sample strata, which were used in the fourth phase’s survey.
5.3.4.5 *The fourth case*

Table 5-8 is the brief of the fourth case.

<table>
<thead>
<tr>
<th><strong>Basic facts</strong></th>
<th><strong>Process improvement</strong></th>
</tr>
</thead>
</table>
| 1. Integrated Project Delivery.  
2. Incentives in cost, time and other functionality.  
3. The General Contractor (GC) and 25 to 50% of all Specialty Contractor (SC)’s participated in setting incentives. | 1. Concurrent design of process and product: Always.  
2. 25 to 50% of all SCs participated in process design.  
5. Inventory management of materials: Rarely.  

<table>
<thead>
<tr>
<th><strong>Point Based Design</strong></th>
<th><strong>Set Based Design</strong></th>
</tr>
</thead>
</table>
| 1. Designers’ starting their works only after the previous designers’ having finished their works: Never. | 1. The GC participated in making the expected cost  
2. 25 to 50% of all SCs participated in making the expected cost.  
3. The GC’s investigation of the best practices before design: Yes.  
4. 25 to 50% of all SCs participated in design.  
5. Decomposition of the contractual cost into components: Yes.  
6. 25 to 50% of all SCs participated in the decomposition of the contractual cost.  
7. Designers’ consulting other designers: Sometimes.  
8. Designers’ consulting the GC: Often.  

<table>
<thead>
<tr>
<th><strong>Production control</strong></th>
<th><strong>Production control</strong></th>
</tr>
</thead>
</table>
| 1. All handoffs in a phase were defined before the phase.  
2. 75 to 100% of all SCs participated in phase scheduling.  
3. Correction of a wrong decision made in the master schedule by a phase scheduling: Often.  
4. How many aspects were considered in the constraint analysis: 62.5% of the first case.  
5. Timing of constraint analysis: before less than 1 week.  
6. 25 to 50% of all SCs did constraint analysis.  
7. None of SCs did a first run study.  
8. Correction of a wrong decision made in a phase schedule by a constraint analysis: Sometimes.  
9. 25 to 50% of all SCs investigated the next workers’ readiness  
10. 25 to 50% of all SCs had instant communication channels with adjacent workers.  
11. Correction of a wrong decision made in a constraint analysis by a weekly work plan: Rarely.  
12. Removal of the causes of the weekly work plans’ failures: Rarely.  
13. SCs investigation if the causes of the weekly plans’ failures were removed: Sometimes. |
Contrary to the Korean cases mentioned above (the first, second and third cases), the general contractor and the main specialty contractors participated in setting incentives and making product design in this project. In terms of ‘early involvement of contractors,’ ‘incentives’ and ‘design to cost,’ this project showed more positive Lean appearance than the Korean cases. This project was categorized as an Integrated Project Delivery (IPD) project.

Cohen et al. (2010) defined the six main characteristics of an IPD System in view of the American Institute Association (AIA), which are:

(a) Early involvement of Key participants
(b) Shared risk and reward
(c) Multi party contract
(d) Collaborative decision making and control
(e) Liability waivers among key participants
(f) Jointly developed and validated project goals.

An additional literature review, of which name was not revealed in this paper for the protection of this project’s privacy, showed that the fourth case satisfied all the six characteristics of an IPD project. The literature also showed that this project had relatively steeper performance criteria, such as LEED sustainability goals and tight schedule that would not have been possible by traditional DBB or CM at Risk, from the beginning. I came to think that the flat performance indicators (cost reduction plus schedule reduction percentage) that were used in this research might not be an absolute criterion without serious consideration of difficulty but this concern is beyond this research.

One of the interesting features of this project was a big change in the scope. The pure value over 30% of the original budget was added and approximately 55% of the value was added by cost-plus subcontracts within an incentive compensation layer. This project used the incentive effectively to increase value with less waste. With the traditional methods, they would have undergone many reworks in doing change orders. Actually, one of the participants of this project said that he/she learned that close collaboration with builders made the redundant detailed designing processes unnecessary.

In conclusion, this project showed good processes following the principles having produced the survey instrument. This showed that ‘incentives,’ ‘early involvement of builders in design’ and ‘production control practices’ were the keys leading desirable outcomes.
5.3.4.6 The fifth case

Table 5-9 is the brief of the fifth case.

Table 5-9: Brief of the fifth case

| General features | 1. Traditional Design-Bid-Build but past performance was the first criteria in selecting the bidder.  
2. No incentive in both design and construction. | Production Control | 1. None of all specialty contractors participated in a phase scheduling.  
2. Specialty contractors checked the next workers’ readiness: Sometimes.  
3. Specialty contractors used pulling principle: Sometimes.  
4. Specialty contractors removed the causes of the past plan failures: Sometimes.  
5. Specialty contractors checked the success of the weekly plan: Sometimes |
|------------------|-------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|
| Set Based Design | 1. They never reviewed and narrowed down the design alternatives.  
2. Designers’ consulting contractors: Sometimes. | Protection Control | 1. None of all specialty contractors participated in a phase scheduling.  
2. Specialty contractors checked the next workers’ readiness: Sometimes.  
3. Specialty contractors used pulling principle: Sometimes.  
4. Specialty contractors removed the causes of the past plan failures: Sometimes.  
5. Specialty contractors checked the success of the weekly plan: Sometimes |
| Process improvement | 1. The concurrent design of product and process never happened. | Protection Control | 1. None of all specialty contractors participated in a phase scheduling.  
2. Specialty contractors checked the next workers’ readiness: Sometimes.  
3. Specialty contractors used pulling principle: Sometimes.  
4. Specialty contractors removed the causes of the past plan failures: Sometimes.  
5. Specialty contractors checked the success of the weekly plan: Sometimes |

This case recorded the lowest performance among all the projects in Figure 5-24. The impressively lower score in performance was mainly due to too big a delay of the project schedule. However, before discussing delay of the project schedule, Table 5-9 shows that this project was also far from the implementation of Lean Construction. For example, none of the specialty contractors participated in a phase scheduling, which was a rare thing among the projects having participated in this phase’s survey. Similarly, the respondent said this project’s subjective quality was very low, which was also an unusual response compared to other survey responses in this phase.

In addition, the respondent pointed out all the items provided by the survey as the factors causing the unsatisfactory performance, which are:

(a) Time consuming government administration.
(b) Methods of selecting contractors.
(c) Owner’s reluctance to change from traditional ways.
(d) Contractors’ reluctance to change traditional ways.
(e) Architects’ reluctance to change traditional ways.
(f) Design engineers’ reluctance to change traditional ways.
(g) Specialty contractors’ reluctance to change the traditional ways.

Let alone Lean Construction, this project seemed to have a lot of room to be improved. However, even if we considered the overall aspects mentioned before, the performance indicator was too low.
An additional interview revealed that the all extension in duration had been approved by the owner. The owner of the project increased the scope during the original contractual period and granted the additional time. To speak strictly, there was no duration increase according to the respondent’s comment. If the owner admitted all the elongation, there is no delay in project duration in this survey measurement. The performance indicator of this project came from the respondent’s misunderstanding about the survey question.

5.3.4.7 The sixth case

Table 5-10 is the brief of the sixth case, of which items were collected by a questionnaire surveys.

Table 5-10: Brief of the sixth case

<table>
<thead>
<tr>
<th>Brief explanation</th>
<th>Production Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. DBB.</td>
<td>1. None of the handoffs of a phase were determined before the phase.</td>
</tr>
<tr>
<td>2. Contract with negotiation.</td>
<td>2. None of the SCs participated in the phase scheduling.</td>
</tr>
<tr>
<td>3. Private contract without bidding.</td>
<td>3. Correction of a wrong decision made in the master schedule by a phase scheduling: Often.</td>
</tr>
<tr>
<td>4. Project Financing (PF).</td>
<td>4. How many aspects were considered as constraint analysis: 75% of the first case.</td>
</tr>
<tr>
<td>1. 0 to 25% of Specialty Contractors (SCs) participated in process designing.</td>
<td>5. Starting time of SCs’ constraint analysis of a work: 1 to 6 weeks before execution of the work.</td>
</tr>
<tr>
<td>2. Minimization of batch sizes of materials: Sometimes.</td>
<td>6. 0 to 25% of all SCs had instant communication channels with the adjacent SCs.</td>
</tr>
<tr>
<td>3. Standardization of materials/processes: Sometimes.</td>
<td>7. 0 to 25% of all SCs did constraint analysis.</td>
</tr>
<tr>
<td>4. Inventory management: Never.</td>
<td>8. 0 to 25% of all SCs did a first run study.</td>
</tr>
<tr>
<td>5. Preassembly of materials: Often.</td>
<td>9. Correction of a wrong decision made in a phase schedule by a constraint analysis: Sometimes.</td>
</tr>
</tbody>
</table>

Interestingly, it did not use a competitive bidding based on the least price. It used a private contract with negotiation. There was a reason. This project used the Project Financing (PF) in which the GC invests his/her own money to build the project first and will be paid back as the profits is generated by the operation of the project’s facilities.
This was really interesting because the GC of a PF project probably tries to reduce the unnecessary money/time more to cope with the bigger future uncertainty than that of a normal project of which cost is paid by the owner first. In addition, he or she probably tried to participate in the feasibility study of the project to see if his/her investment could be paid back with some guaranteed profits.

However, Table 5-10 shows some strange things. For example, none of the handoffs in a phase were defined before the phase. In addition, none of SCs participated in the phase scheduling. Most of the scores were less than those of the first case but the performance of this project was better than that of the first case. Thus, I suspected that the respondent did mistakes in answering the survey questions so that I decided to ask the respondents some questions used in the survey again. The result of the interview is in A.8.

As I expected, the GC of the sixth project participated in the feasibility study and the design as well as he/she tried to reduce the unnecessary cost/time to cope with the future uncertainty because this project was a PF project constructed by the GC’s investment first. Thus, I concluded that the relevant parts of his survey response were done by mistakes.

The general contractor agreed that most parts of the Lean production theory were effective but there was limit for him to apply the principles to the real world perfectly. Due to his correction of the previous responses, many parts of the survey were changed so that the independent variable, the degree of ‘Lean Construction’ was changed from 4.9241 to 6.8134. Similarly, the predicted dependent variable was also changed from -9.132 to -2.6893. However, the observed dependent variable of this project was 29.1523, as we saw in section 5.3.4.1, which was too high even after the correction of independent variable. Thus, I looked over again the spread sheet to see if there had been any mistake in data input. As a result, I found that I had input the design cost into calculating the performance by my mistake. In addition, I had considered the cost increase in design as the cost reduction! When I eliminated the design cost performance as I had done in calculating other projects’ performance, the performance indicator of this project was changed to Zero much nearer to the predicted dependent variable, -2.6893.

One of the interesting features of the Korean Construction Industry found in this interview is the SCs are not chosen until the overall scheduling is determined. According to the interviewee of this project, it is a rare thing for a SC to participate in scheduling let alone participate in design. I felt that the notion that the downstream player in construction does not need to participate in the upstream decision is much more prevalent in Korea than in the other nations.
5.3.4.8 Findings from case studies

Table 5-11 summarizes the result of the case study. The ‘Treatment’ described in Table 5-11 also included the direction of modifying the survey instrument for the next third and fourth phases. Another treatment that I want to say here was the change of performance indicator in the fourth phase’s survey on the Korean Construction Industry. Judging from the result of the second phase survey and of the case studies, Most Korean did not seem to understand the concepts, approved budget and approved schedule. All of them used lump-sum price contract, which requested neither cost reduction nor schedule reduction. Every contractor has his/her profit in the lump-sum price and the percentage of the profit is not revealed to the owner. If they can maintain the percentage, the bigger contractual cost means more profit so that it is ridiculous thing for any contractor to reduce the lump-sum contractual cost in Korea. On the contrary, every contractor tries to increase his/her lump-sum contractual cost by intentional change orders. In fact, all the Korean projects showed cost overrun or schedule overrun in the fourth phase’s survey. Measuring the cost reduction from an approved budget might be meaningful in the USA construction industry, of which contractual structure includes incentivized fee or reimbursable cost but it is not in Korea. Thus, I decided to replace approved budget with initial contractual cost in the performance indicator used in the fourth phase’s survey on Korean projects.

Table 5-11: Summary of the case study

<table>
<thead>
<tr>
<th>Classification</th>
<th>Characteristics</th>
<th>Findings</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>The First Case</td>
<td>A ‘Model Building’ case to find out the causal factor of the too good performance. Lean Construction: 5.5928. Performance: 22.7273. Predicted performance: -6.8517.</td>
<td>The wrong inclusion of the design performance in calculating the overall performance by mistake lead to the exaggerated performance.</td>
<td>1. Deleting the design performance changed the performance from 22.7273 to -6.9215, much nearer to the predicted performance, -6.8517. 2. For the detail of the minor changes such as modification of the survey questions, see Ch.5.3.4.1.</td>
</tr>
<tr>
<td>The Second Case</td>
<td>A ‘Model Building’ case to find out the causal factor of the too bad performance. Lean Construction: 6.8381. Performance: -22.8964. Predicted performance: -2.6052.</td>
<td>It used the ‘long term continuous contract’ that had not guaranteed the annual budget so that there had been too big uncertainty in funding from the beginning.</td>
<td>Adding a question asking if it used the ‘long term continuous contract’ in the fourth phase’s survey for better interpretation but not diversifying the sampling according to the contract type because whether the owner managed the contract type can be regarded as the degree of constraint analysis and it can be measured by the previous survey.</td>
</tr>
<tr>
<td>The Third Case</td>
<td>A ‘Model Testing’ case to see if the internal processes were supported by the theory that had produced the survey. Lean Construction: 5.5043. Performance: -8.6069. Predicted performance: -6.9829.</td>
<td>The construction parties knew well the production theory that had produced the survey. Even they used a ‘long term continuous contract’ the same as the second case, the contractor was guaranteed the annual budget to a certain degree. In addition, the general contractor also tried to reduce project variability caused by funding.</td>
<td>Minor change: ‘all the specialty contractors’ in the previous version was changed to ‘all the main specialty contractors’ in the new version (the next phase) based on the interview of this case.</td>
</tr>
<tr>
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<td>--------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>The Fourth Case</td>
<td>A ‘Model Testing’ case to see if the internal processes were supported by the theory. Lean Construction: 7.9787. Performance: 0.8622. Predicted performance: 1.284.</td>
<td>It showed good processes developed based on the ‘Lean Construction.’ It is an IPD project.</td>
<td></td>
</tr>
<tr>
<td>The Fifth Case</td>
<td>A ‘Model Building’ case to find out the causal factor of the too bad performance. Lean Construction: 4.6762. Performance: -103.07. Predicted performance: -9.9772.</td>
<td>It was the respondent’s misunderstanding of the question about performance. The interview with the respondent showed that all change orders were approved by the owner.</td>
<td>The performance was changed from -103.07 to 0 because all approved budget and schedule cannot influence the performance indicator.</td>
</tr>
<tr>
<td>The Sixth Case</td>
<td>A ‘Model Building’ case to find out the causal factor of the too good performance. Lean Construction: 4.9241. Performance: 29.1513. Predicted performance: -9.1318.</td>
<td>1. The ‘Project Financing’ that this project employed should have been regarded as having incentives even though there was no specified contractual incentive. 2. The respondent answered the survey questions without sufficient consideration. 3. I input the design performance into overall performance by mistake.</td>
<td>1. The fourth phase survey on Korean projects used the question, ‘if your project used Project Financing, please recall that there are any incentivizing factors to improve performance even though there was not any specified contractual incentive. If there is any incentivizing factor, please select about which the incentivizing factors were among money, time or other performance.’ 2. Based on the interview asking the same questions in the survey, the independent variable was changed from 4.9241 to 6.8134.</td>
</tr>
</tbody>
</table>
According to this change, the predicted dependent variable was changed from -9.1318 to -2.6893.

3. The dependent variable was changed from 29.1513 to 0, much nearer to the predicted dependent variable, -2.6893.

| Overall cases | 1. The first and the second case showed that the performance data gotten from the government could be unrealistic or unreliable.  
2. Most Korean respondents understood well the questions comprising Table 5-1, the original form before that abbreviated to Table 5-2 and 5-3 used in producing Figure 5-24, and the response rate in Korean was much higher than that outside of Korea because I am an officer of the relevant government agency having easier contacts to the contractors so that this research did not need to abbreviate the survey for fear of the low response rate. | 1. I decided to use different performance indicator in Korea, \((\text{initial contractual cost-actual cost})/\text{initial contractual cost} + (\text{initial contractual schedule-actual schedule})/\text{initial contractual cost}\), instead of the previous one, \((\text{approved budget-actual cost})/\text{actual cost} + (\text{approved schedule-actual schedule})/\text{actual schedule}\).  
2. The Korean survey for the fourth phase would take the form represented by Table 5-1 while the survey on the purposive sample comprised of Lean Projects would take the form represented by Table 5-2 and Table 5-4. |
5.4 The third phase of data collection

With the same way as described in Ch. 5.3.1, the members of this purposive sample were gathered continuously after the second phase. One thing that I wanted to say about the measurement of contractors’ participation in design and in feasibility study in the third phase was proven not to be appropriate to be quantified. For example, the survey measurement asked the respondents to specify the project type (e.g., housing, office or health care) and asked them to specify all the Specialty Contractors (SCs) having participated in design. However, I came to know that there was no method to generalize the main SCs according to building type as a result of some investigation. For example, when we see an invitation to bid for SCs, the number of items in the bid invitation could often be more than 20. Every project has its own unique features that cannot be generalized. Thus, I decided to use the measurement described in Table 5-1 for the next fourth phase’s survey on the Korean industry instead of the measurement described in the third column of Table 5-3 used for this third phase’s survey. As for other measurements’ scoring, this phase’s survey followed the principles described in Table 5-2 and Table 5-3.

The difference between the second phase and the third phase is that the third phase did not contain any Korean project because I decided to use different performance indicators in the Korean projects as a result of the case studies as Table 5-11 shows. In addition, I decided to exclude the data from Brazil because they used the ‘official budget’ instead of the ‘approved budget’ and the ‘official budget’ is similar to the ‘initial contractual cost’ used in the fourth phase’s survey on Korea. The concept, ‘approved budget,’ is more complicated than that of ‘official budget’ or that of ‘initial contractual cost’ because the ‘approved budget’ contains added scopes or change orders that an owner agreed. To eliminate the confusion in performance indicator, I excluded Korean projects and Brazilian projects for this phase and added more Lean projects from other nations.

5.4.1 Results of the survey in the third phase

5.4.1.1 Performance and Lean Construction in the third phase

The regression line between performance (Y) and Lean Construction (X) is Y=1.18X-2.96 and it is not significant as Figure 5-25 and Table 5-12 show. The p value of the coefficient of X, 1.18, in the regression line is 0.19. The R squared is just 0.046 and the adjusted R squared that considers the degree of freedom of variables in the model is 0.021. Before rejecting our research hypothesis, I decided to continue investigating each component of Lean Construction. For information, the word, ‘model’ in Table 5-12 means the partition of the total variance which can be explained by the regression line. The word, ‘residual’ means the partition of the total variance which cannot be explained by the regression model.

---

47 See the third column in Table 5-3
48 More detail is explained in A.9
49 The survey used in Brazil was translated to Portuguese by some Brazilian specialists. When I retranslated the Portuguese survey into English by Google translator, the approved budget was represented as ‘official budget.’ The Brazilian specialists said it was difficult for them to translate some terminologies to their language because the Brazil’s situation is not the same as that of America.
### Table 5-12: The basic statistics of Figure 5-25

<table>
<thead>
<tr>
<th>Source</th>
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<th>MS</th>
<th>Number of object = 40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>167.03</td>
<td>1</td>
<td>167.0260</td>
<td>F(1, 38) = 1.82</td>
</tr>
<tr>
<td>Residual</td>
<td>3484.52</td>
<td>38</td>
<td>91.7243</td>
<td>Probability &gt; F = 0.19</td>
</tr>
<tr>
<td>Total</td>
<td>3652.55</td>
<td>39</td>
<td>93.6551</td>
<td>R-squared = 0.046</td>
</tr>
</tbody>
</table>

Adjusted R-squared = 0.021

Root Mean Square Error = 9.58

| Coefficient | Std Errors | T    | P>|t| | 95% confidence Interval |
|-------------|------------|------|------|------------------------|
| X in Figure 5-26 | 1.18       | 0.87 | 1.85 | **0.19** | .59 | 2.94 |
| Constant    | -2.96      | 7.00 | -0.42| 0.67                   | -17.13 | 11.20 |

Figure 5-25: Regression line between performance and Lean Construction in the third phase
5.4.1.2 Performance and incentive in the third phase

The regression line between incentive (X) and performance (Y) is \( Y = 1.9093X - 6.8239 \) and it is significant. The p value of the coefficient of X in Figure 5-26 is 0.049 as Table 5-12 shows. The R squared is 0.0979 and the adjusted R squared is 0.0742. Figure 5-26 describes the linear regression model and Table 5-13 shows the basic statistics of the model in Figure 5-26.

Table 5-13: The basic statistics of Figure 5-26

<table>
<thead>
<tr>
<th>Source</th>
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<th>Number of object = 40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>357.77</td>
<td>1</td>
<td>357.77</td>
<td>F(1, 38) = 4.13</td>
</tr>
<tr>
<td>Residual</td>
<td>3294.78</td>
<td>38</td>
<td>86.70</td>
<td>Probability &gt; F = 0.049</td>
</tr>
<tr>
<td>Total</td>
<td>3652.55</td>
<td>39</td>
<td>93.66</td>
<td>R-squared = 0.098</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Adjusted R-squared = 0.074</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Root Mean Square Error = 9.31</td>
</tr>
</tbody>
</table>

| Coefficient | Std Errors | T      | P>|t|  | 95% confidence Interval |
|-------------|------------|--------|------|---------------------|
| X in Figure 5-27 | 1.91 | 0.94 | 2.03 | 0.049 | 0.0065 | 3.81 |
| Constant    | -6.82      | 6.60   | -1.03| 0.38    | -20.19 | 6.54 |

Figure 5-26: Regression between Incentives and performance in the 3\(^{rd}\) phase
5.4.1.3 Performance and Set Based Design in the third phase

The regression line between Set Based Design (X) and Performance (Y) is \( Y = 0.47 \times X + 5.37 \) and this line is never significant. The p value of this line’s slope is 0.83. I cannot say why this happened with confidence but the reasons can be that the respondent might not be able to locate the right answers to the survey instrument because Set Based Design is relatively new technique in Lean Construction field, or can be that the survey measurement might not be sufficient to measure the concept, Set Based Design. As Table 5-3 shows, there were only 3 questions asking the concept in the survey instrument. Figure 5-27 and Table 5-14 are a graphical representation and relevant statistics respectively.

<table>
<thead>
<tr>
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<th>MS</th>
<th>Number of object = 40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>4.78</td>
<td>1</td>
<td>4.78</td>
<td>( F(1, 38) = 0.05 )</td>
</tr>
<tr>
<td>Residual</td>
<td>3644.30</td>
<td>38</td>
<td>95.90</td>
<td>Probability &gt; F = 0.82</td>
</tr>
<tr>
<td>Total</td>
<td>3652.55</td>
<td>39</td>
<td>93.66</td>
<td>R-squared = 0.0013</td>
</tr>
</tbody>
</table>

Adjusted R-squared = -0.0250

Root Mean Square Error = 9.80

| Coefficient | Std Errors | T      | P>|t|  | 95% confidence Interval |
|-------------|------------|--------|------|-------------------------|
| X in Figure 5-28 | 0.47       | 2.11   | 0.22 | 0.83                    | -3.80 | 4.74 |
| Constant    | 5.37       | 4.23   | 1.27 | 0.21                    | -3.20 | 13.94 |

Figure 5-27: Regression line between performance and Set Based Design in the third phase
5.4.1.4 Performance and Process Improvement in the third phase

The linear regression line between process improvement (X) and performance (Y) is 
Y=6.01X+0.46 with the p value, 0.086, which is not significant. I want to say that the 
measurement was too simple to measure this concept again before making any conclusion about 
this. Of course, process improvement could not be effective in improving project performance as 
the result said. Table 5-3 shows there are only two questions for measuring process improvement.
Figure 5-28 and Table 5-15 describe the relation between process improvement and performance.

Table 5-15: The basic statistics of Figure 5-28

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>275.95</td>
<td>1</td>
<td>275.95</td>
<td>F(1, 38) = 3.11</td>
</tr>
<tr>
<td>Residual</td>
<td>3376.60</td>
<td>38</td>
<td>88.86</td>
<td>Probability &gt; F = 0.086</td>
</tr>
<tr>
<td>Total</td>
<td>3652.55</td>
<td>39</td>
<td>93.66</td>
<td>R-squared = 0.076</td>
</tr>
</tbody>
</table>

Adjusted R-squared = 0.051

Root Mean Square Error = 9.43

| Coefficient | Std Errors | T     | P>|t| | 95% confidence Interval |
|-------------|------------|-------|------|-------------------------|
| X in Figure 5-29 | 6.01       | 3.41  | 1.76 | 0.086                   | -0.89 12.92 |
| Constant    | 0.46       | 3.61  | 0.13 | 0.899                   | -6.85  7.77 |

Figure 5-28: Regression line between performance and process improvement in the third phase
5.4.1.5 Performance and Last Planner™ in the third phase

The Linear regression model between Last Planner (X) and performance (Y) is $Y=5.41X-12.45$ with a significant p value, 0.012. Compared to the p values of Set Based Design and process improvement, this regression model supports the linear correlation between Last Planner and performance much better. The R squared is 0.16 and the adjusted R squared is 0.13. Judging from this phenomenon, I concluded that Last Planner™, the older and more famous technique than Set Based Design (SBD) and process improvement in Lean Construction field showed its better contribution to performance than those two aforementioned newer techniques because most of the respondents understood Last Planner™ better and knew how to locate the implementation of Last Planner™ better in answering the survey questions. In addition, the number of the questions measuring Last Planner™ in this survey measurement is five as Table 5-2 shows, which was bigger than those of questions having measured SBD and process improvement.

Considering that Last Planner™ could be the biggest part of Lean Construction to most of the respondents, Figure 5-30 and Table 5-15 supports this research’s hypothesis that the implementation of Lean Construction will enhance the performance of construction projects.

![Figure 5-29: Regression line between Last Planner™ and performance in the third phase](image-url)
One of the interesting observations from Figure 5-29 is the variables seem to follow a curve more than a line as the regression function. Thus, I made a new independent variable, X squared, in which X is the X in Figure 5-30. The new regression model is $Y = 0.83 \times X^2 - 4.11$ and its p value is 0.009 less than 0.012, that in Table 5-16, and the adjusted R squared is 0.14 bigger than that (0.13) in Table 5-16. This new variable makes better prediction. The result is described in Figure 5-30, which shows Last Planner™ (X) improves performance speedier than the linear increase in Figure 5-29. When I did the same thing with X cubed, I did not find any additionally improved prediction.

![Figure 5-30: Regression line between Last Planner™ squared and performance in the third Phase](image-url)
5.4.2 Conclusion in the third phase

The only components having shown significance in their relations with performance are Last Planner™ and incentives (with contractors’ participation in feasibility study, which I called ‘based on integrity’ afterward). After this finding, I tried to make a multi variate regression model with the two independent variables (Last Planner™ and incentive) in order to get a better regression model. Because Last Planner™ squared showed the more predictable regression model, I used it instead of Last Planner in making the multi variate regression model.

The result is interesting. The multi variate regression model is performance = 0.71×Last Planner™ squared+0.61×incentive-6.70 and the adjusted R squared of the multi variate regression model is 0.13, which is less than that of the regression model with only Last Planner™ squared in Figure 5-30, 0.14. Judging from this, I suspected that there might be a serious correlation between the two independent variables. If one of the two variables can be explained by the other one, the multi variate regression model might not produce a better fitness.

As expected, the coefficient of the correlation between Last Planner™ squared and the incentive is 0.6188 and the p value is 0.0000. They are severely interdependent to each other even though they measured totally different things. This means that the respondents tended to use both of the two independent variables at the same time based on their experiences in which they had come to know the simultaneous usage of both of them improved the project performance significantly. In conclusion, Last Planner™ and incentives based on integrity are indispensable to each other in improving project performance. Figure 5-31 is the scatter plot between the two variables.

![Figure 5-31: Regression line between Last Planner™ squared and incentives in the third phase](image-url)
5.4.2.1 Supplementary information from the third phase.

The Reliability test and the Validation test of the survey measurement discussed in Ch. 4.4 could not be done in this phase. As for the reliability test and convergent validation test, there was no person who would answer the same survey again. As for the discriminant validation test, the two questions made for that test were deleted in the third phase during the process of shortening the volume of the survey.

The third phase survey was disseminated only to the General Contractors (GC). As the survey in the first phase did in section 5.2.2, this phase’s survey also asked what should be improved for better performance. Even though the biggest number of GCs pointed out ‘owners’ reluctance to change’ as the cause hindering ‘performance,’ most of the causal factors listed in the survey question had evenly distributed portions. Figure 5-32 is the summary of the results.

Figure 5-32: Causes harming performance in view of the third phase survey respondents
5.5 The fourth phase of data collection

The total number of projects from Korea is 86. The stratified random sampling strategy described in the later part of Ch. 4.5 was used in this phase. The number of the Government projects Combining design and construction contractually (GC) is 30 among the total 312 projects in this category, the number of the Government projects Separating design and construction contractually (GS) is 24 among the total 1958 projects in this category, the number of the Private projects Combining design and construction contractually (PC) is 16 among the total 201 projects and the number of the Private projects Separating design and construction contractually (PS) is 16 among the total 3409 projects. The first plan was to gather 100 projects in each category but I gathered only the aforementioned numbers of projects.

5.5.1 Results of the fourth phase

5.5.1.1 Performance and Lean Construction in the fourth phase

According to Figure 5-33 and Table 5-16, Lean Construction has a significant correlation with performance in the Korean Construction Industry. The linear regression model between Lean Construction (X) and performance (Y) is $Y=1.44X-52.27$ with the p value, 0.011.

Figure 5-33: Regression line between performance and Lean Construction in the fourth Phase
Table 5-17: Basic statistics of Figure 5-33

<table>
<thead>
<tr>
<th>Source</th>
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<th>Number of object = 86</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3607.28</td>
<td>1</td>
<td>3607.28</td>
<td>F(1, 34) = 6.78</td>
</tr>
<tr>
<td>Residual</td>
<td>44711.28</td>
<td>84</td>
<td>532.28</td>
<td>Probability &gt; F = 0.011</td>
</tr>
<tr>
<td>Total</td>
<td>48318.54</td>
<td>85</td>
<td>568.45</td>
<td>R-squared = 0.075</td>
</tr>
</tbody>
</table>

Adjusted R-squared = 0.064

Root Mean Square Error = 23.07

| Coefficient | Std Errors | T     | P>|t| | 95% confidence Interval |
|-------------|------------|-------|------|------------------------|
| X in Figure 5-34 | 1.41 | 0.54  | 2.60 | **0.011** | 0.33 | 2.49 |
| Constant | -52.27 | 13.15 | -3.98 | 0.000 | -78.41 | -26.12 |

Before concluding that the research hypothesis is significantly supported by the survey on Korea, I decided to see if the sample strata influenced performance other than Lean Construction. I believed that the stratification of the sample is not totally different from the Lean Construction because the stratification was determined by the degree of contractors’ collaboration in design/feasibility study and by the owner’s tendency to achieve efficiency, both of which are among the basic principles having created Lean Construction. However, the stratification could show totally different behavior from Lean Construction in predicting performance. In that case, regression model could be revised with the stratifications as new independent variables.

Using STATA v.10, I made a regression model with the same X and Y used in Figure 5-34 in each stratum (GS, GC, PS and PC) in order to see if the regression model between X and Y maintained the significance in each stratum. The result is described in Table 5-18.

Table 5-18: Regression lines between performance and Lean Construction in the sample strata in the fourth phase

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Regression model between Lean Construction (X) and performance (Y)</th>
<th>P value of the coefficient of X in the model</th>
<th>R squared of the model</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC</td>
<td>Y=1.02X-38.93</td>
<td>0.3</td>
<td>0.038</td>
</tr>
<tr>
<td>PC</td>
<td>Y=0.81X-38.30</td>
<td>0.40</td>
<td>0.051</td>
</tr>
<tr>
<td>GS</td>
<td>Y=1.14X-58.61</td>
<td>0.54</td>
<td>0.078</td>
</tr>
<tr>
<td>PS</td>
<td>Y=0.70X-22.71</td>
<td>0.25</td>
<td>0.052</td>
</tr>
</tbody>
</table>

Table 5-18 shows that all the regression between Lean Construction and performance lost its significance. Each stratum takes on homogeneous features of both Lean Construction and performance. If a stratum shows a significant line between Lean Construction and performance, we can say another causal factor of Lean Construction not relevant to the stratification strongly determines performance but Table 5-18 didn’t show such case. Thus, I concluded that the stratification played a decisive role in characterizing the independent variable, Lean Construction, in terms of influencing performance.
To reaffirm this conclusion, I investigated if different strata showed different values in Lean Construction as well as in performance and if the differences supported the regression model in Table 5-17. To investigate this argument, I did Analysis of Variance (ANOVA) tests of performance and of Lean Construction by the strata. If there is significant difference in Lean Construction and performance between the strata and the difference is coincident with the hypothesis supported by Table 5-17, we can say the strata determined the Lean Construction and the determined value of Lean Construction subsequently determined performance. In that case, we don’t need to separate the strata as new independent variables influencing performance. If not, we should make a new regression model with the strata being new independent variable.

Table 5-19 is the result of the ANOVA test of performance by the sample strata. The worst group is GS (Government Separating), whose sum of the cost overrun and the schedule delay was 34.60% on an average, and the best group is the PS (Private Separating), whose sum of the cost overrun and the schedule delay is 6.38%. The worst group was understandable but the best group was hard to understand to a certain degree. If the contractors’ participation in design was the only dominant causal factor, the best group should be one of GC or PC. At this point, I came to think that the owners’ tendency pursuing efficiency can be another dominant factor determining performance and I suspected that there might be systematic problems in the Korean projects combining design and construction, GC and PC. This is discussed in more detail in section 5.5.1.5 and in section 6.5. Figure 5-34 is a graphical representation of the average performance of each stratum.

Table 5-19: ANOVA test on performance by the sample stratification in the fourth phase

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC</td>
<td>-12.97</td>
<td>19.61</td>
<td>30</td>
</tr>
<tr>
<td>PC</td>
<td>-17.70</td>
<td>21.47</td>
<td>16</td>
</tr>
<tr>
<td>GS</td>
<td>-34.60</td>
<td>27.73</td>
<td>24</td>
</tr>
<tr>
<td>PS</td>
<td>-6.38</td>
<td>14.33</td>
<td>16</td>
</tr>
</tbody>
</table>

The ANOVA table is below

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Degree of Freedom</th>
<th>Mean of Squares</th>
<th>F value</th>
<th>Probability &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between strata</td>
<td>9490.80</td>
<td>3</td>
<td>3163.60</td>
<td>6.68</td>
<td>0.0004</td>
</tr>
<tr>
<td>Within strata</td>
<td>38827.76</td>
<td>82</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>48318.56</td>
<td>85</td>
<td>568.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bartlett’s test for equal variance</td>
<td>Chi2(3) = 7.66</td>
<td></td>
<td></td>
<td>Probability&gt;Chi2=0.054</td>
<td></td>
</tr>
</tbody>
</table>

The author assumed that private projects’ owners have stronger will to pursue efficiency than the public projects owners when he set the stratification.
The ANOVA in Table 5-19 shows that the stratification influenced performance significantly. The p value is 0.0004, much less than 0.05. The Sum of squares of ‘between strata’ is the partition of the total variance, which can be explained by the stratification, while the sum of squares of ‘within strata’ is the partition, which cannot be explained by the stratification. For information, the Bartlett’s test’s null hypothesis is that every stratum has equal variance within the stratum and if the probability > Chi 2 is less than 0.05, the null hypothesis is rejected. The Bartlett’s null hypothesis is an important assumption in using an ANOVA test. In this case, even though the null hypothesis is not rejected, it is at the edge of the rejection.

An ANOVA test assumes that the variance within each stratum is same. The Bartlett’s test of this ANOVA test, with the p value of 0.054, shows that there could be a violation of this assumption. Thus, if the assumption is rejected by some test such as ‘sdtest’ in STATA, I had to do the T-test or the unequal Welch T-test per each pair of the strata instead of depending only on an ANOVA test. As a result, there were significant differences of performance between:

(a) GC (Mean: -12.97) and GS (Mean: -34.60) with the p value, 0.0015

(b) PS (Mean:-6.38) and GS (Mean: -34.60) with the p value, 0.0002

(c) PC (Mean: -17.70) and GS (Mean:-34.60) with the p value, 0.0466

As for the (c) in the right above, it is not easy to decide that there is significant difference between the two strata. However, definitely, the performance of GS was much worse than that of GC and PS. To see if this finding is coincident with the difference of Lean Construction among the strata, I did another ANOVA test of Lean Construction by the strata.
The ANOVA in Table 5-20 showed that the stratification influenced Lean Construction significantly. The p value is 0.0024, much less than 0.05. Figure 5-35 is a graphical representation of the different means of the performance among the strata.

Table 5-20: ANOVA test of Lean Construction by the sample strata in the fourth phase

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC</td>
<td>24.35</td>
<td>3.75</td>
<td>30</td>
</tr>
<tr>
<td>PC</td>
<td>25.46</td>
<td>6.05</td>
<td>16</td>
</tr>
<tr>
<td>GS</td>
<td>21.15</td>
<td>3.23</td>
<td>24</td>
</tr>
<tr>
<td>PS</td>
<td>23.24</td>
<td>4.61</td>
<td>16</td>
</tr>
</tbody>
</table>

The ANOVA table is below

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Degree of Freedom</th>
<th>Mean of Squares</th>
<th>F value</th>
<th>Probability &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between strata</td>
<td>290.39</td>
<td>3</td>
<td>96.80</td>
<td>5.22</td>
<td>0.0024</td>
</tr>
<tr>
<td>Within strata</td>
<td>1519.11</td>
<td>82</td>
<td>18.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>48318.56</td>
<td>85</td>
<td>568.45</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bartlett’s test for equal variance

Chi2(3) = 8.56

Probability>Chi2=0.036

Figure 5-35: Means of Lean Construction according to the sample strata in the fourth phase
However, the Bartlett’s test with the p value, 0.036, in Table 5-20 shows that the assumption of ANOVA test could be violated so that I did the T-test or the unequal Welch T-test per each pair of the strata. As a result, there were significant differences of Lean Construction between

(d) PC (Mean: 25.46) and GS (21.15) with the p value, 0.0056
(e) GC (Mean: 24.35) and GS (21.15) with the p value, 0.0001

(a), a result of the ANOVA test of performance, is coincident with (e), a result of the ANOVA test of Lean Construction and (c), a result of the ANOVA test of performance, is coincident with (d), a result of the ANOVA test of Lean Construction. Roughly, the ANOVA tests support that the stratifications are important features determining Lean Construction in predicting performance.

Because the GS projects had the least collaboration of contractors in making design and the least incentive encouraging the owners to pursue better performance in nature, they got the lowest score in Lean Construction as well as performance and their lowest score contributed to make the significant regression model between Lean Construction and performance. Because the behavior of each stratum complies with Lean Construction and performance in supporting the research hypothesis, we did not need to separate the stratification as new variables.

At this point, we can guess intuitively that the main component of Lean Construction that contribute to improve Korean project’s performance probably is Set Based Design (SBD) because SBD represents the degree of contractors’ collaboration for design and efficiency, which are the basic concepts having made the strata. To confirm this intuition, I continued investigating each component of Lean Construction such as SBD, incentive, process improvement and Last Planner™.
5.5.1.2 Performance and Incentive in the fourth phase

The regression model between incentives (X) and performance (Y) is $Y = 2.26\times X-30.83$ with the P value, 0.087. This model is not significant. The adjusted R squared is just 0.0233. To see if this kind of insignificance of the regression model between X and Y continues in each stratum, I did regressions in each stratum. Table 5-21 is the result. None of the strata showed any significance.

For further investigation, I did a similar ANOVA test of incentive by the sample strata. Table 5-21 is the result and there was no significantly different degree of ‘incentive’ among the strata. This is natural. All of the Korean projects adopted a Lump sum contract, which rarely used contractual incentives.

Table 5-21: Regression lines between performance and incentive in the sample strata in the fourth phase

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Regression model between Lean Construction (X) and performance (Y)</th>
<th>P value of the coefficient of X in the model</th>
<th>R squared of the model</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC</td>
<td>$Y=2.36X-26.49$</td>
<td>0.32</td>
<td>0.036</td>
</tr>
<tr>
<td>PC</td>
<td>$Y=0.95X-23.22$</td>
<td>0.73</td>
<td>0.0085</td>
</tr>
<tr>
<td>GS</td>
<td>$Y=-2.92X-21.34$</td>
<td>0.48</td>
<td>0.023</td>
</tr>
<tr>
<td>PS</td>
<td>$Y=1.91X-17.04$</td>
<td>0.15</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Table 5-22: ANOVA test of incentives by the sample strata in the fourth phase

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Degree of Freedom</th>
<th>Mean of Squares</th>
<th>F value</th>
<th>Probability &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between strata</td>
<td>22.94</td>
<td>3</td>
<td>7.65</td>
<td>2.04</td>
<td>0.11</td>
</tr>
<tr>
<td>Within strata</td>
<td>307.10</td>
<td>82</td>
<td>18.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>330.04</td>
<td>85</td>
<td>3.88</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bartlett’s test for equal variance

Chi2(3) = 11.55

Probability>Chi2=0.009

In conclusion, the ‘Incentive’, one of the components of ‘Lean Construction,’ did not show any significant influence on ‘Performance’ of the Korean Projects and one of any stratum did not show any significantly different ‘Incentive’ compared to the others.

5.5.1.3 Performance and Process Improvement in the fourth phase

The regression model between process improvement (X) and performance (Y) is $Y = 3.09\times X-32.37$ with the p value, 0.12. This model is not significant. The adjusted R squared is just 0.017. To see if this kind of insignificance of the regression model between X and Y continues in each stratum, I did regression in each stratum. Table 5-23 is the result. None of the strata showed any significant regression model between X and Y.

Table 5-24 shows the stratification influence process improvement. Considering the p value of the Bartlett’s test for equal variance in Table 5-24, I did T-test or Unequal Welch T test on each pair of the strata based on whether a pair violated the ANOVA test’s assumption that the variance within each stratum is same. As a result, there were significant differences of process improvement between:
(a) GS (Mean: 4.99) and PC (Mean: 3.89) with the p value, 0.014
(b) GS (Mean: 4.99) and GC (Mean 4.66) with the p value, 0.013

Table 5-23: Regression lines between process improvement and performance in the sample strata in the fourth phase

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Regression model between Lean Construction (X) and performance (Y)</th>
<th>P value of the coefficient of X in the model</th>
<th>R squared of the model</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC</td>
<td>$Y=2.34X-23.89$</td>
<td>0.45</td>
<td>0.0210</td>
</tr>
<tr>
<td>PC</td>
<td>$Y=1.61X-25.74$</td>
<td>0.68</td>
<td>0.012</td>
</tr>
<tr>
<td>GS</td>
<td>$Y=3.33X-47.58$</td>
<td>0.62</td>
<td>0.011</td>
</tr>
<tr>
<td>PS</td>
<td>$Y=0.21X-7.28$</td>
<td>0.93</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

Table 5-24: ANOVA test of process improvement by the sample strata in the fourth phase

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Degree of Freedom</th>
<th>Mean of Squares</th>
<th>F value</th>
<th>Probability &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between strata</td>
<td>13.72</td>
<td>3</td>
<td>4.57</td>
<td>2.83</td>
<td>0.043</td>
</tr>
<tr>
<td>Within strata</td>
<td>132.39</td>
<td>82</td>
<td>1.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>146.11</td>
<td>85</td>
<td>1.72</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bartlett’s test for equal variance $\text{Chi}^2(3) = 7.4847$ Probability $>\text{Chi}^2=0.058$

In conclusion, the Government projects Separating design and construction (GS) implemented much more process improvement than the Government/Private projects Combining design and construction (GC/PC) but this difference did not influence performance to a significant degree. Even though GS projects tried to improve construction processes more than others significantly, their performance was worst among all strata. There can be two interpretations. The first interpretation is that process improvement based on Value Stream Analysis is not effective to improve Korean construction processes and the second interpretation is that process improvement is not recognized appropriately in Korea. I think that the second interpretation is more reasonable, based on the interview with the general contractors of the third case (A.6) and on the interview with an anonymous contractor on Apr. 26, 2009 (A. 40). In the two interviews, the interviewees commonly said Value Engineering is another form of change order. Even though Value Engineering in Korea is not directly related to process improvement, they have a common feature to create more value to customers. Judging from that VE has not been used to improve performance but to justify a change order, process improvement might be used to justify other concepts or used to be advertised for something else.
5.5.1.4 Performance and Last Planner™ in the fourth phase

The regression model between Last Planner™ (X) and performance (Y) is $Y = 1.12 \times X - 29.87$ with the P value, 0.43. This model is not significant. The adjusted R squared is just -0.0043. To see if this kind of insignificance continues in the regression model between X and Y in each stratum, I did a regression per each stratum. Table 5-25 is the result. None of the strata showed any significant regression model.

Table 5-25: Regression lines between Last Planner™ and performance in the sample strata in the fourth phase

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Regression model between Lean Construction (X) and performance (Y)</th>
<th>P value of the coefficient of X in the model</th>
<th>R squared of the model</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC</td>
<td>$Y=0.62X-18.72$</td>
<td>0.78</td>
<td>0.0028</td>
</tr>
<tr>
<td>PC</td>
<td>$Y=2.25X-38.36$</td>
<td>0.54</td>
<td>0.028</td>
</tr>
<tr>
<td>GS</td>
<td>$Y=4.67X-78.59$</td>
<td>0.17</td>
<td>0.086</td>
</tr>
<tr>
<td>PS</td>
<td>$Y=-1.03X+2.97$</td>
<td>0.60</td>
<td>0.020</td>
</tr>
</tbody>
</table>

The subsequent ANOVA test of Last Planner™ by the strata did not show any significant difference among the strata in Table 5-25. This is not surprising to me because there might be few respondents, who understood what Last Planner™ is. If the respondent did not know what he/she answers, their responses might be meaningless.

However, I believed that the more important reason is in the tradition of selecting specialty contractors in Korea. The interviewee in the sixth case (A.43) said it was not natural for a Korean project to allow specialty contractors to participate in process design because they are usually selected after the completion of the overall schedules. Similarly, an e-mail from a respondent (on Nov. 25, 2010, it is not in the appendices) said that the survey instrument did not reflect the reality of the Korean Construction Industry since it requested to measure the degree of the specialty contractors’ participation in process design.

In conclusion, because there was little room for specialty contractors to participate in scheduling, measuring specialty contractors’ production control such as Last Planner™ might be meaningless in Korea. Table 5-1 recommends that Last Planner™ urge specialty contractors to schedule proactively and to do constraint analysis.
5.5.1.5 Performance and Set Based Design (SBD) in the fourth phase

The regression model between SBD (X) and ‘Performance’ (Y) is \( Y = 4.53 \times X - 37.47 \) with the p value, 0.003. This model is significant. The adjusted R squared is 0.087. Table 5-26 and Figure 5-37 show the result.

![Figure 5-36: Regression line between Set Based Design and Performance in the fourth phase](image-url)

Table 5-26: The basic statistics of Figure 5-36

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>Number of object = 86</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>4707.13</td>
<td>1</td>
<td>4707.13</td>
<td>F(1, 34) = 9.07</td>
</tr>
<tr>
<td>Residual</td>
<td>44711.28</td>
<td>84</td>
<td>532.28</td>
<td>Probability &gt; F = 0.0034</td>
</tr>
<tr>
<td>Total</td>
<td>48318.54</td>
<td>85</td>
<td>568.45</td>
<td>R-squared = 0.095</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Adjusted R-squared = 0.087</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Root Mean Square Error = 22.79</td>
</tr>
</tbody>
</table>

| Coefficient | Std Errors | T     | P>|t| | 95% confidence Interval |
|-------------|------------|-------|------|-------------------------|
| X in Figure 5-37 | 4.53        | 1.50  | 3.01 | **0.003** | 1.54 | 7.52 |
| Constant     | -37.47     | 6.71  | -5.58| 0.000       | -50.82| -26.12 |

As I expected in the last paragraph of section 5.5.1.7, SBD showed a significant correlation with Performance. However, I suspected that most of the Korean respondents understood SBD in a biased way because SBD is a relatively new concept in Lean Construction field, which the respondents of the Lean Projects had difficulty in answering the relevant questions as we saw in section 5.4.1.3.
To figure out this situation, I investigated the validity of this measurement of SBD by comparing with the survey question asking Point Based Design (PBD), which is the opposite concept to SBD. That is a kind of discriminant validation test described in section 4.4.

More interestingly, PBD had a severe positive correlation with SBD with the p value, 0.008, which means most of the Korean respondents believed they collaborated with other construction parties to make designs while they designed under a severely hierarchical and point-based decision making system (Figure 5-37). If SBD and PBD had been measured correctly, the correlation between the two concepts should have been significantly negative. Of course, PBD allows collaboration to a degree but the main difference between SBD and a collaborative design under PBD is the concurrency of collaboration. All the relevant parties collaborate at the same time in SBD while each relevant party contributes to the design at separate time in PBD.

Lean Construction asserts that there would probably be unnecessary reworks under PBD condition. I agree that PBD would produce much more unnecessary iterations if the construction parties have to produce many different design alternatives to construct much difficult projects. However, if they are to construct stereo-typed facilities and main decisions were already made at the beginning, what each party in design has to do is to review constructability of the decisions using its specialized knowledge without making new and creative alternative decisions. Under this condition, a timely series of the specialized processes could be efficient as a plant produces mass products. I do not think that the construction projects demanding a large degree of creativity are dominant in Korea. Anyway, I found that the Korean Construction Industry has been good at designing with collaboration separated in time and it is better at it with more disintegrated responsibility.

![Figure 5-37: Regression line between Point Based Design and Set Based Design in the fourth phase](image)

\[ Y = 2.99X + 2.42 \]
In fact, the relevant Korean Acts have made PBD inevitable. According to the 11th provision of the Electrical Framework Act on the Construction Industry, government agencies should separate electrical construction works from an overall construction project contractually. In the same manner, the 25th provision of the Communication Framework Act on the Construction Industry forces public owners to separate communication construction works from an overall construction project contractually. As for engineering, this trend is also maintained as we saw the interview with the architect of the first case (② of the A.3). Thus, we can conclude that the contractual barriers have also led PBD to be dominant in the Korean Construction Industry.

However, the fact that Korean used PBD with collaboration separated in time, apparently similar to SBD, does not mean that they do not employ individual techniques of SBD. The further statistical analysis51 showed that the Korean respondents used well the main techniques of SBD such as ‘collaborative decomposing the contractual cost into construction components’, ‘designers’ consulting the relevant contractors’, ‘reviewing design alternatives52’, and ‘narrowing down design alternatives based on constraint analysis.’ Judging from this, they seemed to know the benefits of the individual techniques of SBD. In addition, the interviewee of the Sixth case also supported this expectation by saying that the methodologies described as SBD in the survey had been a traditional form of design in Korea (A.3).

The significant correlation between SBD and Performance was already expected by intuition in section 5.5.1.1. The ANOVA tests of Lean Construction and Performance by the sample strata showed that the stratification determines the level of Lean Construction as well as that of performance and the determined Lean Construction and performance are correlated to each other, which makes us believe the stratification is a strong independent variable of Lean Construction in predicting performance. Because SBD is most similar to the concepts of the sample stratification (integration of design and construction; and attitudes toward efficiency), I expected only SBD would show a strong correlation with performance. This expectation was already proven by Table 5-26 and the other components including incentives, process improvement and Last Planner™ failed to show such strong correlations with performance in section 5.5.1.2, Ch. 5.5.1.3 and Ch 5.5.1.4.

As I did in the previous sections, sections 5.5.1.1 to sections 5.5.1.4, I did regressions between SBD (X) and performance (Y) in each stratum in order to see if a significant correlation between X and Y exists in each stratum. As a result, the regression model in each stratum lost its previous significance, which it had in Table 5-26. Thus, I confirmed again that the strata determined SBD’s main characteristics in predicting performance. The result is Table 5-27.

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Regression model between Set Based Design (X) and performance (Y)</th>
<th>P value of the coefficient of X in the model</th>
<th>R squared of the model</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC</td>
<td>Y=1.86X-22.49</td>
<td>0.53</td>
<td>0.015</td>
</tr>
<tr>
<td>PC</td>
<td>Y=3.96X-37.63</td>
<td>0.18</td>
<td>0.12</td>
</tr>
<tr>
<td>GS</td>
<td>Y=4.75X-47.31</td>
<td>0.66</td>
<td>0.009</td>
</tr>
</tbody>
</table>

51 The statistical analysis is done on the sub components of SBD. Table 5-26 and Figure 5-36 used the one aggregated variable comprising SBD but this analysis used disaggregated variables to see the individual behavior of sub components of SBD.
52 Of course, I suspect that these alternatives are not fully creative alternatives. The difference among the alternatives might be smaller than that used in ‘Lean Construction’
Another confirmation of that the stratification characterized SBD was done by another ANOVA test of SBD by the sample strata. As expected, the strata influenced SBD significantly. The p value is 0.000. The result is in Table 5-28.

However, the Bartlett’s test with the p value, 0.000 in Table 5-28 requested me to do several t tests (based on equality or un-equality of ‘within group variance’ among strata) per each pair of strata. The individual t test showed that there were significantly differences of SBD between:

(a) GS (Mean of ‘Set Based Design’: 2.68) and PS (Mean: 3.70) with the p value, 0.0096
(b) PS (Mean: 3.70) and PC (Mean: 5.03) with the p value, 0.030
(c) GS (Mean: 2.68) and PC (Mean: 5.03) with the p value, 0.0002
(d) GC (Mean: 5.12) and PS (Mean: 3.70) with the p value, 0.0009
(e) GC (Mean: 5.12) and GS (Mean: 2.68) with the p value, 0.0000

At this point, we need to recall the result of t tests of performance by the strata in section 5.5.1.1 in order to see if the ANOVA test of performance by the sample strata is coincident with the ANOVA test of SBD by strata in supporting the research hypothesis having been supported by Table 5-26.

According to the result in Ch. 5.5.1.1, there were the significant differences of ‘Performance’ between:

(f) GC (Mean: -12.97) and GS (Mean: -34.60) with the p value, 0.0015
(g) PS (Mean:-6.38) and GS (Mean: -34.60) with the p value, 0.0002
(h) PC (Mean: -17.70) and GS (Mean:-34.60) with the p value, 0.047

The (f) in the right above is coincident with the (e) in terms of supporting the research hypothesis, the (g) in the right above is coincident with the (a) and (h) in the right above is coincident with the (c). In conclusion, the two results of T-tests, done on both SBD and performance, support the regression model in Table 5-26 and Figure 5-36 represents. Based on this result, I was sure that did not need to separate the stratification as new independent variables to predict performance.

Another interesting thing is found when I did a t-test between the projects combining (GC and PC) and the projects separating (GS and PS) instead of the four strata. As for performance, the projects combining are much worse than the projects separating with the p value, 0.012. As for SBD, there is not a significant difference between the two. Judging from this, I concluded that
there might be another factor other than whether a Korean project combines design and construction characterizing SBD in terms of predicting performance.

I assert that the ‘another’ thing is owner’s tendency toward performance improvement, whether a project is a public one or a private one. A private owner tries to reduce unnecessary cost/time because those are his/her own money and time while a public owner does not necessarily do that. Thus, the four strata address a project more precisely among the coordinate system comprised of Lean construction and performance than the two strata.

A more detailed investigation shows that this symptom is partly due to too good performance of the Private projects Separating design and construction (PS) and partly due to the relatively bad performance of the Private projects Combining (PC). This result shows that there might be systematic problems in the projects combining (GC or PC) in pursuing better performance. We can confirm this by seeing the comparison between the projects combining and the projects separating in terms of money spent and frequency of being used. If there had been problems in PC, They would have been much less frequently/costly used than PS. As I expected, PC has been used much less than PS in the private sector as Table 5-29 shows. This trend is same in comparison of the money spent between PC and PS in the private sector. Private sector’s owners seemed not to take the projects combining due to some problems.

Table 5-29: Comparison of usages among the sample strata from 2004 to 2009

<table>
<thead>
<tr>
<th>Kinds of the Projects</th>
<th>Number of the projects</th>
<th>Money used for the projects (billion won)</th>
<th>C/S in number</th>
<th>C/S in money</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC</td>
<td>312</td>
<td>21426.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC</td>
<td>201</td>
<td>11469.1</td>
<td>Private sector: 201/3409=5.89%</td>
<td>Private sector: 11469.1/151462.5=7.57%</td>
</tr>
<tr>
<td>PS</td>
<td>3409</td>
<td>151462.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Judging from Table 5-29, the public sector’s owners seemed to be encouraged to use the projects combining (GC) by government policy while the private sector’s owner did not.
5.5.2 Conclusion in the fourth phase

Apparently, Lean Construction improved the Korean projects’ performance but this might be solely due to Set Based Design. The other components of Lean Construction such as incentive, Last Planner™ and process improvement did not show significant contribution to performance.

Set Based Design in Korea has limits in being fully used because of the relevant Act system forcing the public owners to separate contracts for a project and because of the general projects’ characteristics not demanding intensive and concurrent reviewing creative design alternatives, which might be required in very difficult and complex projects. In addition, most of the respondents believed that they had used Set Based Design fully even though they had employed Point Based Design to a high degree. In similar context, Set Based Design has a significant correlation with Point Based Design statistically. This is because they had been accustomed to collaborate for design with severe contractual barriers and because this tradition made most of the Korean respondents confused in understanding fully the survey questions.

Additional interviews revealed that a well arranged point based decision making with a certain level of collaboration, which does not necessarily demand timely concurrent collaboration among relevant parties, has been regarded as a best practice in this nation’s industry. However, this does not mean they didn’t know the individual skills of SBD such as how to review design alternatives based on constraint analysis. Most of the respondents had known the importance of collaboration between constructors and designers in producing design and they actually achieved desirable performance thorough those kinds of collaboration, which might not be exactly the same as the collaboration that Lean Construction pursues.

Set Based Design is deeply related to the category comprised of ‘Government projects Combining design and construction (GC),’ ‘Government projects Separating design and construction (GS),’ ‘Private projects Combining construction and design (PC)’ and ‘Private projects Separating (PS).’ Several T-tests comparing performance between the categorized groups are coincident with the other T-tests comparing Set Based Design between the groups in supporting the hypothesis that ‘Set Based Design’ improves ‘Performance.’ Conclusively, the sample strata did not need to be separated as other independent variables to predict performance because the strata showed coincident behavior with Lean Construction in predicting performance, which means they are interdependent to each other.

Judging from the additional T-tests, the projects combining design and construction, regardless of whether they were public or private projects, seemed to have problems in getting desirable performance so that private sector’s owners tended not to take that kind of projects. Further investigation of the current regulations addressed the problems that the projects comling have in Chapter 6 Policy Recommendation.
5.5.3 Supplementary information collected in the fourth phase

This chapter did the similar analysis to that having been done in section 5.2.2.

5.5.3.1 Survey for the owners in the fourth phase

(a) 51% of the owners pointed out ‘the cost submitted by the bidders’ as the most important bid feature. Only 14% of them did ‘the past performance of similar projects’ as the most important bid feature. Total six features were evaluated and this question allowed multiple choices. Figure 5-38 is the summary of the result.

(b) 41% of the owners agreed that contractors will inflate the cost or schedule of a project if they participate in the design of the project for their own benefit or for the more buffers to cope with the future uncertainty. Figure 5-39 is the summary of the results.
(c) 37% of the owners agreed that there had been a problem in selecting appropriate bidders while 16% of them disagreed with that. Figure 5-40 shows the summary of the results.

![Figure 5-40: Owners’ recognition of problems in the current procurement of contractor in the fourth phase](image)

(d) 63% of the owner agreed that if past performance of the similar projects becomes an absolute criterion evaluating bidders, every contractor will try to achieve better performance than that specified in contracts while 11% of them disagreed with that. Figure 5-41 is the summary of the results.

![Figure 5-41: Owners’ recognition of performance as an absolute bid criterion in the fourth phase](image)
(e) 33% of the owners pointed out ‘government related works, such as legal approvals,’ as the biggest culprit hindering performance. Figure 5-42 is the summary of the results.

Figure 5-42: Causes harming performance in view of DBB owners in the fourth phase

5.5.3.2 Survey for the architects of projects separating design and construction

(a) 38.9% of the architects agreed that if contractors participate in the design of a project, they will inflate the cost or schedule of the project for their own benefits or for the bigger buffers to cope with the future uncertainty while 21.3% of them disagreed with it.

(b) The government-related things are the most popular cause hindering project performance, which was chosen by the architects. The detail is in Figure 5-43.

Figure 5-43: Causes harming performance in view of DBB architects in the fourth phase
5.5.3.3 Survey for general contractors in the fourth phase

(a) 58% of the general contractors agreed that if a specialty contractor participates in design, he/she will inflate the cost/schedule for his/her own benefit or for bigger buffer to cope with the future uncertainty while 21% of them disagree with that. The detail is in Figure 5-44.

(b) 75% of the general contractors agreed that if a design is not specific enough, the owner will order to do more works while 7% of them disagreed with it. Figure 5-45 is the summary of the results.

Figure 5-44: General contractors’ distrust in specialty contractors in the fourth phase

Figure 5-45: General contractors distrust in owners in the fourth phase
(c) 43% of the general contractors agreed that the current procurement of a general contractor has problems in selecting an appropriate contractor while 15% of them disagreed with it. The detail is in Figure 5-46

![Figure 5-46: General contractors’ recognition of problems in the current procurement of contractors in the fourth phase](image)

(d) 57% of the contractors agreed that if the past performance becomes an absolute criterion in selection of the best bidders, every contractor tries to achieve better performance than that specified in contracts while 9% of them disagreed with that. Figure 5-47 is a summary of the results.

![Figure 5-47: General contractors’ recognition of performance as an absolute bid criterion in the fourth phase.](image)
(e) 26% of the contractors pointed out ‘owners’ being reluctance to change’ as a culprit hindering the project performance. The second most popular causal factor is ‘government-related matters such as legal approvals. Figure 5-48 shows the summary of the results.

Figure 5-48: Causes harming performance in view of general contractors in the fourth phase
5.5.3.4 Conclusion about the supplementary information in the fourth phase

Table 5-30 is the summary of the supplementary information in Chapter 5. An interesting finding is the degrees of trust among construction parties in Korea are lower than those of Lean Projects outside of Korea. Most of the Korean owners believed that if a contractor participated in design, he or she would inflate the cost/duration for his or her own benefits or for more buffers to cover the future uncertainty. Similarly, most of the contractors believed that if a design was not concrete enough, the owner of the project would order more works than necessary. Their belief reflects the real Korean industry. Thus, they have been accustomed themselves to the strong hierarchical, disintegrated and contractual structure to protect themselves from the distrustful circumstances.

The barriers that the hierarchical, disintegrated and contractual structure produced makes Value Engineering another form of change order (section 5.5.1.3), prohibits specialty contractors from scheduling proactively based on their constraint analysis (section 5.5.1.4) and develops Set Based Design to a biased form (In fact, their SBD was a PBD with collaborations separated in time, section 5.5.1.5).

Table 5-30: Summary of the supplementary information in Chapter 5

<table>
<thead>
<tr>
<th>Lean Projects combining design and construction in the first phase</th>
<th>Lean Projects separating design and construction in the first phase</th>
<th>Korean Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The most important bid feature</strong></td>
<td>‘Bidders’ understanding of the project’ chosen by 42.9% of the owners.</td>
<td>‘Cost submitted by bidders’ chosen by 41.67% of the owners.</td>
</tr>
<tr>
<td><strong>Owner’s distrust in contractors as for inflation of cost/time in design</strong></td>
<td>29% of them distrusted and 57.2% of them trusted.</td>
<td>25.2% distrusted and 43.8% of them trusted.</td>
</tr>
<tr>
<td><strong>General contractors’ distrust in owners as for overworks.</strong></td>
<td>60% of them distrusted and 10% trusted.</td>
<td>36% of them distrusted and 18% trusted.</td>
</tr>
<tr>
<td><strong>General contractors’ distrust in specialty contractors as for inflation of cost/time in design.</strong></td>
<td>58% of them distrusted and 21% trusted.</td>
<td></td>
</tr>
<tr>
<td><strong>Architects’ distrust in contractors as for inflation of cost/time in design.</strong></td>
<td>11% of them distrusted and 78% trusted.</td>
<td>38.9% of them distrusted and 21.3% trusted.</td>
</tr>
<tr>
<td><strong>Recognition of problems in the current procurement of</strong></td>
<td>1. 43% of the owners felt that the current system is not appropriate.</td>
<td>1. 50% of the owners felt the current system is not appropriate.</td>
</tr>
<tr>
<td>contractors</td>
<td>2. 33% of the GCs felt the current system is not appropriate but 44% did not.</td>
<td>2. 56% of the GCs did it.</td>
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<tr>
<td>Agreements that the past performance as an absolute criterion improves performance</td>
<td>1. 85.8% of the owners agreed with it.  2. 80% of the GCs agreed with it.</td>
<td>1.78.5% of the owners agreed with it  2. 54% of the GCs did it</td>
</tr>
<tr>
<td>The most popular culprit hindering performance in view of owners</td>
<td>1. 100% of the owners chose ‘time consuming government affairs.’  2. 100% of the GCs chose ‘owners’ being reluctance to change.’</td>
<td>1. The architects’ being reluctance to change chosen by 37% of the owners.  2. The owners’ being reluctance to change chosen by 100% of the GCs. (As for the third phase, it was chosen by 16% of the GCs.)  3. The owners’ being reluctance to change chosen by 100% of the architects.</td>
</tr>
</tbody>
</table>
CHAPTER 6 POLICY RECOMMENDATION

The survey of the third phase, which investigated the relation between Lean Construction and project performance on the projects that were known to have employed Lean Construction, revealed that Last Planner™ (production control based on plan reliability) and Incentive based on integrity had strong correlations with project performance. The fourth phase’s survey on the Korean Construction Industry showed that Set Based Design had been significantly correlated with project performance. In addition, the distrustful circumstances of the Korean construction industry have developed some concepts addressed by Lean Construction in biased ways. For example, SBD in Korea is another form of a Point Based Design (PBD) with collaborations separated in time. Value Engineering (VE) in Korea is another form of a change order. An incentive is meaningless because all Korean construction projects adopt lump-sum price contracts without any incentivizing fee and any reimbursable cost. Last Planner™ is also meaningless because specialty contractors are chosen after a general contractor has set most of the schedules.

Based on the results of the third/fourth phases’ surveys, I make policy recommendations according to the major project delivery systems in this chapter. The following are the principles in making the recommendations arrayed in Table 6-1. The detailed contents are discussed in section 6.1 to section 6.8.

<Principle 1>: If the Korean construction parties had known Last Planner™, they would have shown a similar result to that of the Lean projects’ group in the third phase’s survey. Thus, I encourage the industry to employ Last Planner™ in their contractual structures.

<Principle 2>: Even though Incentive based on integrity showed a significant correlation with project performance in the Lean Projects, it is not easy to introduce directly any incentive system having been used in the USA or other countries to the Korean industry because the most prevalent contract type is a lump-sum price contract, in which any incentive is not appropriate, and based on which overall relevant regulations has been developed. Instead, based on the result summarized in Table 5-29, in which most of the respondents agreed that past project performance as an absolute bid feature would help enhance performance and that the existing procurement of contractor, which has focused only on a bid price/duration, is not appropriate to maintain the market competitiveness, I urge the industry to make the past project performance more dominant in the bid evaluation criteria so that this bid evaluation criterion works as an incentive to pursue a better performance.

<Principle 3>: Because the contractual separation has developed SBD into the biased form of a PBD, I urge the industry to eliminate those kinds of contractual barriers.

<Principle 4>: Because the Korean project delivery system combining construction and design, such as the Design-Build and the Alternate Design-Bid, showed they had had unknown causal factors interfering project performance implicitly as we saw in Table 5-28, I investigated relevant regulations with some indirect statistical analysis aside from those having been used in Chapter 5 to find out the causal factors so that I made recommendations to cure the causal factors. The detailed contents are described in section 6.5.

<Intuition>: Some recommendations are directly supported by this research’s findings but the others are not. Thus, I marked (e.g., supported by <principle 1>) and ordered all recommendations based on the degree of being supported by the research findings. The recommendations made based on intuition that stems from the review of relevant regulations are marked as ‘supported by intuition.’
<table>
<thead>
<tr>
<th>Project Delivery System</th>
<th>Current state/Facts</th>
<th>Future state/Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[a] There is no specification evaluating ‘Lean Construction,’ such as production control based on plan reliability, integrated design of process and product in the bid evaluation criteria.</td>
<td>[A] Owners are encouraged to embed Lean Construction in their invitation to bid or bid evaluation criteria so that the bidders specify the strategy how to control production based on plan reliability when they submit the bid documents.</td>
</tr>
<tr>
<td></td>
<td>→ Following &lt;principle 1&gt;</td>
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<td></td>
<td>[b] Because Lean Construction is a totally new concept to the Korean Construction Industry, a simple instruction about how to implement ‘Lean Construction’ might not be appropriate now.</td>
<td>[B] The government does several pilot projects so that it develops customized implementations of Lean Construction and disseminates them as best practices.</td>
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<td></td>
<td>→ Following &lt;principle 1&gt;</td>
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<tr>
<td></td>
<td>[c] Evaluation of the past similar projects’ performance is not enough to reflect bidders’ capability to build.</td>
<td>[C] Performance of past similar projects, such as cost reduction/schedule reduction/safety accident rate, takes more dominant role in bid evaluation criteria.</td>
</tr>
<tr>
<td></td>
<td>→ Following &lt;principle 2&gt;</td>
<td></td>
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<tr>
<td></td>
<td>[d] There is no reliable record of past project performance even though the current regulation requires public owners to record project performance at completion if the presumed project cost is more than 50 billion Korean won.</td>
<td>[D] The government agency establishes a database containing past project performance and uses the database in awarding future projects.</td>
</tr>
<tr>
<td></td>
<td>→ Following &lt;principle 2&gt;</td>
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<td>164</td>
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<tr>
<td>[e] If someone was already registered as an owner of an architectural firm, he/she cannot be registered as an owner of a construction company. There is a very severe job barrier between construction and design. → Following &lt;principle 2&gt;</td>
<td>[E] An architectural firm can do the work of a construction company if it is qualified. In the same way, a construction company can do the works of an architecture firm as long as it is qualified.</td>
<td></td>
</tr>
<tr>
<td>[f] Electrical and communication construction works are separated from the rest of the construction project by regulations. This has produced disintegrated work ethics and unnecessary rework getting through the contractual barriers. → Following &lt;principle 2&gt;</td>
<td>[F] The relevant provisions of the Korean Acts are deleted such as the 11th provision of the ‘Electrical Framework Act on the Construction Industry’ and the 25th provision of the ‘Communication Framework Act on the Construction Industry.’</td>
<td></td>
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<tr>
<td>[g] The Long Term Continuous Contract (LTCC) does not guarantee the annual budget plan, which gives the general contractor high uncertainty in constructing the project. → Following &lt;principle 1&gt;</td>
<td>[G] LTCC is deleted from the relevant regulation.</td>
<td></td>
</tr>
<tr>
<td>[h] The size of the presumed cost of a project has been the main criterion in determining the project delivery system and there is not clear reason that this should be the main criterion. → Supported by intuition</td>
<td>[H] There are more reasonable criteria in determining a project delivery system by presumed cost and there are more reasonable guidelines for owners selecting appropriate project delivery system based on the project’s characteristics such as level of difficulty and complexity.</td>
<td></td>
</tr>
<tr>
<td>[2] Design-Build (DB), Alternate Design-Bid (ADB), Technical Proposal Bid (TPB), and Technical</td>
<td>[a] The ‘basic executive plan,’ basis on which a project delivery system is determined, includes only the name, a brief explanation, the presumed cost, the presumed duration, the construction location, the bidding time, the preferred project delivery system and the reason for selecting the</td>
<td>[A] There is a more specific and reasonable guide line of making a basic executive plan of a project so that the CCTDC determines what type of project delivery system is appropriate for the project.</td>
</tr>
<tr>
<td><strong>Competition (TC)</strong></td>
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<td>project delivery system. This information is insufficient for the ‘Central Construction Technology Deliberation Committee (CCTDC)’ to determine the project delivery system.</td>
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<td>→ Supported by intuition</td>
<td></td>
<td></td>
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</tbody>
</table>

[b] A ‘Design Consulting Committee (DCC)’ starts investigating the appropriateness of the detailed design that the selected bidder has submitted.  
→ Supported by intuition

**[B]** A DCC is involved in the design processes while the selected bidder is making a detailed design.

[c] If a government officer, who works for the relevant central government agency in the field of civil engineering, is higher than $4^{th}$ level $^{53}$, he can be appointed to be a member of the CCDTC or the DCC.  
→ Supported by intuition

[C] If a government officer is to be appointed a member of the CCDTC or a DCC, he/she should be a professional engineer or should have an equivalent or higher degree in the relevant field.

[d] Having a masters/PhD degree or a Professional Engineering certificate in relevant technical field is not taken into account by human resource management in decision regarding government officers’ careers.  
→ Supported by intuition

[D] The relevant government agency embeds incentives in its human resource management in order for its employees to have a masters/PhD degree or a professional engineering certificate in the relevant technical field so that the CCTDC or a DCC enhances the quality of its members.

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**[3] Technical Proposal Bid (TPB) based on schematic design**

[a] Bid evaluation criteria are at owners’ discretion.  
→ Following <principle 1>

[A] The future state is the same recommendation as [1]-[A].

[b] Design Bid Build with an investigation of a capability to build is the most dominant project  

[B] Technical Proposal Bid based on schematic design is the most dominant project delivery

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$^{53}$ There are total 9 levels in the Korean government officers’ job hierarchy. The less level means higher authority.
| **[4] Technical Proposal Bid (TPB) based on detailed design** | delivery system. However, the specifications of this project delivery system prevent owners from implementing Lean Construction in his/her project.  
→ Supported by intuition | system to implement Lean Construction in the industry because this restricts the owner’s freedom to implement Lean Construction less than the DBB, the DB, and the ADB. |
| --- | --- | --- |
| | [c] This project delivery system can be applied only to the projects which involve symbolic representations, commemorative features, artistic value or high level technologies. However, these criteria are too abstract to be addressed.  
→ Supported by intuition | [C] Owners use this project delivery system based on their projects’ characteristics such as level of difficulty or complexity. |
| | [a] Bid evaluation criteria are at owners’ discretion.  
→ Following <principle 1> | [A] The future state is the same recommendation as [1]-[A]. |
| | [b] It is not clear under what conditions an owner should select Technical Proposal Bid based on detailed design instead of Technical Proposal Bid based on schematic design.  
→ Supported by intuition | [B] There are more concrete specifications about when an owner should use this project delivery system instead of Technical Proposal Bid based on schematic design. |
| | [c] A bidder must submit the detailed quantities and prices of materials as the bid documents for a project. Too detailed quantities and prices restrict the project’s flexibility to cope with future uncertainty so that they will cause many change orders during the construction.  
→ Supported by Intuition | [C] A bidder is not requested to submit detailed quantities and prices of materials when he/she participates in the bid of a project using this project delivery system. |
| [5] Design-Build and Alternate Design Bid (DB/ADB) | [a] A schematic design, the most important bid document in these project delivery systems, is too expensive for a small company to make so that only major construction companies have participated in the DB/ADB projects. In addition, the unclear bid evaluation criteria demanding perfect schematic design make the competition more favorable to bigger companies.  
→ Following <principle 4> | [A] A schematic design is simplified much more than the existing one. In addition, there are clearer criteria evaluating a schematic design, such as concrete records about the past similar projects’ performance so that contractors compete under fairer conditions. |
| | [b] There is no bid-evaluation criterion that measures the integrated design of both product and process, and measures the production control based on plan reliability.  
→ Following <principle 1> | [B] The future state is the same recommendation as [1]-[A]. |
| | [c] The Central Construction Technology Deliberation Committee or any Design Consulting Committee should investigate all aspects of a schematic design including plan feasibility, economic feasibility and environmental sustainability.  
→ Following <principle 4> | [C] The schematic design will be simplified and customized to an individual project so that the committees do realistic and efficient evaluations. |
| [6] Alternate Design-Bid (ADB) | [a] After an owner makes a detailed design, bidders submit two bid prices, one for the detailed design that the owner made and the other for an alternate design.  
→ Supported by Intuition | [A] Bidders submit only the alternate Design based on schematic design that an owner provided and the bid price for it. |
<p>| | [b] An alternate Design that a bidder submits as the bid should be superior to the original design that | [B] An owner decides which characteristics of his/her project should take the bidders’ creativity and |</p>
<table>
<thead>
<tr>
<th>[7] Technical Competition (TC)</th>
<th>[a] Bid evaluation criteria are at owners’ discretion. → Following &lt;principle 1&gt;</th>
<th>[A] The future state is the same recommendation as [1]-[A].</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[b] This project delivery system should be used under seriously restricted conditions. → Supported by Intuition</td>
<td>[B] The criteria to use this project delivery system are loosened but clearer so that an owner uses this system based on the actual characteristics of his/her project, such as level of difficulty/complexity, more easily.</td>
</tr>
<tr>
<td>[8] Design-Bid-Build (DBB)</td>
<td>[a] If the presumed cost of a DBB Project is greater than 10 billion Korean won, the owner should do ‘Value Engineering (VE)’ through a separate contract with a third professional party after completion of the original detailed design. → Supported by Intuition</td>
<td>[A] The provision making VE mandatory is removed. If there is anything, which needs to employ bidders’ creativity, in the design that an owner made, it is delivered by an Alternate Design-Bid process.</td>
</tr>
</tbody>
</table>
6.1 Recommendations for every project delivery system

Figure 6-1 describes the general procurement processes of construction project (MCCI, 2009), which are mainly comprised of the bid evaluation criteria or preliminary phases of biddings. The Established Public Accounting Rule (2200.04-147-30, 2010.9.8) known as ‘the rule for a prequalification screening,’ the Established Public Accounting Rule (2200.04-149-26, 2010.9.8) known as ‘the criteria for an investigation of a capability to build’ and the Established Public Accounting Rule (2200.04-163-03, 2010.9.8) known as ‘the bid evaluation criteria for Design-Build/Alternated Design-Bid (DB/ADB) projects’ regulate the bid evaluation criteria or the prequalification screening criteria of DBB or DB/ADB projects. For DBB projects, these bid evaluation criteria largely concern financial credibility, capability to build and the bid price. For DB/ADB projects, they largely concern schematic/detailed design quality and the bid price.

After reviewing the aforementioned regulations, I concluded that there is no provision that enables measuring the degree of a production control based on plan reliability. Thus, I recommend the nation’s industry to embed measurement of a production control in the bid evaluation criteria. This recommendation is based on <principle 1>. That is the recommendation, [1]-[A] in Table 6-1. Even though Last Planner™ did not show any correlation with the Korean project’s performance in section 5.5.1.4, I believe that if the Korean construction participants had known the technique properly, Last Planner™ would have shown a much better correlation with performance as we saw in section 5.4.1.5. Introducing a production control into bid evaluation criteria might be done as follows.

(a) To what extent a consortium produces the process design collaboratively.
(b) To what level of detail a consortium defines the role of each participant in process design.
(c) To what level of detail a consortium specifies the methodologies to find and remove constraints before executing the processes.
(e) To what level of detail a consortium specifies the methodologies to reduce waiting time between adjacent processes.
(f) To what level of detail a consortium specifies the methodologies to execute a work as soon as possible when the next production units are ready to receive the handoffs of the work.
(g) To what level of detail a consortium specifies how to find causes of failure in executing weekly plans and to prevent the failures from happening again.

Lean Construction must be customized to the Korean Construction Industry because Lean Construction has been developed under different circumstances from the Korean industry. We have seen differences in circumstances in the previous chapters. For example, Set Based Design (SBD) in Korea was understood as ‘Point Based Design’ with a separated collaboration in time (section 5.5.1.5), Value Engineering in Korea is another form of a change order (5.5.1.3) and Last Planner™ has been rarely implemented under the normal Korean tradition of selecting subcontractors only when their specific construction works are to be performed (5.5.1.4). As stated [1]-[B], the Korean government agencies are encouraged to do pilot projects in order to find the more customized form of Lean Construction to the Korean industry. The 36th provision of the Enforcement Decree of the Construction Technology Management Act defines how to evaluate past projects’ performance. According to this provision, an owner should evaluate his/her project, and the evaluation records should be open to public so that any owner may use it in selecting contractors of his/her future similar projects. In the similar way, the Established Public Accounting Rule (2200.04-149-26, 2010.9.8) referred to as ‘the criteria for an
investigation of a capability to build’ includes past similar projects’ performance as a criterion to
evaluate a bidder’s capability to build. As for the detailed methodology, the 2010-1044th public
announcement of the ministry of Land, Transport and Marine affairs of South Korea defined the
detailed criteria containing most of the performance indicators listed in Table 3-21 including cost,
schedule, safety, and satisfaction performance.

However, the maximum score of a bidder can get only due to its past similar performance
evaluation is just 1.2 when we set 100 as the maximum score considering all the bid evaluation
criteria of the bidder according to the fifth provision of the Established Public Accounting Rule
(2200.04-149-26, 2010.9.8) known as ‘the criteria for an investigation of a capability to build.’
There is no bid evaluation criterion about the past project performance for DB/ADB projects
according to the Established Public Accounting Rule (2200.04-163-03, 2010.9.8) referred to as
‘the bid evaluation criteria for DB/ADB projects.’ This is the current state/facts described in [c]-
[1] of Table 6-1. [1]-[C] of Table 6-1 recommends that past similar projects’ performance be
dominant in bid evaluation criteria.

According to the 69th provision of the Enforcement Decree of the Construction Technology
Management Act, if the presumed price of a project is more than 50 billion Korean won, the
owner should record the post-project evaluation of the performance but this policy has not been
effective. Most of the owners did not seem to evaluate their relevant projects. According to
MCCI (2009), only 6.45% of the relevant owners did the post-project evaluations in 2005. This
is the existing state that [1]-[d] of Table 6-1 shows and the recommendation is what [1]-[D] of
Table 6-1 suggests.

Another current problem is that an owner is forced to separate certain groups’ works from the
whole project contractually. It is suspected that the relevant regulations are the results of a group-
selfishness among certain job groups. This suspicion was already pointed out in MCCI (2009)
and in many other news articles. The main assertion of the proponents of the separate orders is
that it prevents the big general contractors from exploiting the specialty contractor Of course,
there has been suggested several solutions to this problem, such as the prime contract which
allows the prime contractor (the general contractor) to take responsibility for overall organization
but guarantees the specialty contractors the contracted payment as contractual parties. To give
fair payments among construction participants is obviously important but ‘separate order’ is not
the solution. It destroys project integrity. The current state is shown in [1]-[e] and the [1]-[f] of
Table 6-1. Thus, I urge every qualified person or company be eligible for performing work and
urge deletion of the regulations mandating owners to divide single projects contractually as in
[1]-[E] and [1]-[F] of Table 6-1.

Table 6-1 also addresses the criteria to determine the delivery system of a project. The expected
cost of a project is usually the primary criterion determining the project delivery system. For
example, according to the chapter six of the Enforcement Decree of the Act on Contracts to
Which the State is a Party, if a project’s presumed cost is more than 30 billion Korean won and
if the project is comprised of varied construction works, the owner is encouraged to deliver the
project with Design-Build (DB) or Alternate Design-Bid. (ADB) Similarly, according to the 42nd
provision of the Enforcement Decree of the Act, if the presumed cost of a project is more than 10

56 http://www.koscaj.com/detail.php?number=23101&thread=22r05r02
billion Korean won, the owner is strongly encouraged to use DBB with competitive bidding based on least price.

However, no reasonable rationale has been found for determining project delivery systems based on presumed cost. Government agencies should provide a better rationale or provide new criteria that determine the project delivery system of a project based on its actual characteristics, such as the level of technical difficulty or the level of complexity. The current state is shown [1]-[h] of Table 6-1 and the future state is suggested in [1]-[H].

[1]-[g] of Table 6-1 is about the Long Term Continuous Contract (LTCC), which was the main cause of the poor performance of the second case (section 5.3.4.3). The LTCC guarantees only the total contractual cost of a project not the annual budget, which plays a role as a severe constraint disturbing the work flow of the project. Because work flow is what Last Planner™ tries to maintain to the best of the operator’s capability, I intentionally specified this recommendation is based on <Principle 1> in Table 6-1. The recommendation is to eliminate this provision from the Act as suggested in [1]-[G] of Table 6-1.
General Process (Public Procurement Service)

1. Deliberation through discussion
2. Decision of Project delivery system
3. Invitation to Bid
4. Prequalification for Bid
5. Making Estimated Cost
6. Bidding
7. Selection of the best bidder
8. Evaluation of Construction capacity partly based on defects, and violation
9. Design Build/Alternate Bid
10. Post evaluation of Performance (>50 mil$)

Figure 6-1: General process of construction procurement
6.2 Recommendations mainly for the DB/ADB/TPB/and TC

According to the 58th provision of the Enforcement Decree of the Construction Technology Management Act, the Basic Executive Plan (BEP) of a project is what the Central Construction Technology Deliberation Committee (CCTDC) uses to determine whether the project will be delivered by Design-Build (DB) or Alternate-Design-Bid (ADB). However, the BEP of a project includes only the name, a brief explanation, the presumed cost, the presumed duration, the construction location, the timing of bidding, the project delivery system preferred by the owner and the reason of the preference. To put it simply, the owner should provide the rationale that he/she chooses the DB or the ADB for his/her project and the CCTDC investigates if the rationale is reasonable. However, the document given to the CCTDC for its investigation does not contain the information needed to make a decision. MCCI (2009) also asserted that the documentation should be more concrete, specified and inclusive. That is the current state described in [2]-[a] of Table 6-1. To improve the current state, It is recommended that a BEP contain enough information in order for the CCTDC to do appropriate investigation, which is the future state described in [2]-[A] of Table 6-1. However, the research findings in the Ch 5 do not support directly this fact and the recommendation. This recommendation is made by intuition based on a review on those existing Korean regulations.

Figure 6-2, Figure 6-3 and Figure 6-4 describe the processes of the Technical Proposal Bid (TPB), the DB and the ADB respectively. I made these figures according to the Act on Contracts to which the State is a Party and the Construction Technology Management Act. One of the common things in from Figure 6-2 to Figure 6-4 is an owner’s Design Consulting Committee (DCC) investigates whether the detailed design of the project was appropriately made by the selected bidder (see [2]-[b] of Table 6-1). Their investigation is definitely an additional point based decision making in view of Set Based Design described in section 3.2.3. If the CCTDC or a DCC had been involved in an earlier stage of making the detailed design, there would have been less negative iterations. Hence, the recommendation in [2]-[B] of Table 6-1 that CCTDC/a DCC be involved during the detailed-design process. However, the research findings in the Ch 5 do not support directly this fact and the recommendation. This recommendation is made by intuition based on a review on those existing Korean regulations.

In addition, there are issues in human resource management in the relevant government agency. If a government officer of the relevant government agency, whose job position is higher than the 4th level, even though he/she does not have a professional engineer certificate or a PhD/Masters degree, he/she can be appointed a member of the CCTDC/a DCC (the 10th provision of the Enforcement Decree of the Construction Technology Management Act). It is recommended that should have a Masters/PhD degree or a Professional Engineering certification in order to be appointed a member of the CCTDC/a DCC. The current and future state are shown [2]-[c] and [2]-[C], respectively, of Table 6-1. However, the research findings in the Ch 5 do not support directly this fact and the recommendation. This recommendation is made by intuition based on a review on those existing Korean regulations.

To support [2]-[C] of Table 6-1, the government agencies are strongly urged to incentivize its employee’s having graduate degrees or professional engineering certificates so that the CCTDC or a DCC has more qualified members. In fact, the existing incentive is an additional 50$ in monthly salary, which is nearly nothing compared to the efforts that a government officer spends to acquire a graduate degree or a professional engineering certificate.

57 According to the 80th provision of the Enforcement Decree of the Act on Contracts to Which the State is a Party,
Technical Proposal Bid (creative and complex project)

Basic Consideration & Feasibility study
(presumed cost, and limit of cost increase)

Technical Proposal Bid based on schematic design (type 1)

Basic Plan for construction execution:
reason of choosing this PDS

The Central Construction Deliberation Committee’s determination if this PDS will be used

Invitation to bid ⇒ receiving technical proposal (construction cost/duration, or Life cycle cost reduction, and so on) from qualified Design and Builder consortium (type 1) or from builder (type 2)

Owner’s Design Consulting Committee’s scoring the proposals ⇒ 6 top bidders

Figure 6-2: Processes of a Korean Technical Proposal Bid project
Design Build Process (over 30 bill Won)

Basic Consideration & Feasibility study performed by the owner: presumed cost, limit of cost increase

Basic plan of construction project execution: presumed cost/duration/time/ and location, and reason of choosing DB

The Central Construction Deliberation Committee’s determination of if DB will be used based on the basic plan

Invitation to bid & Prequalification for bid: consortium qualified to do both construction and design

Schematic design, and relevant documents as bids

Owner’s Design Consulting Committee’s deliberation of Schematic Design: Feasibility, Constructability, Maintenance, Safety, Sustainability ⇒ Design Score

Among Six Consortium having been chosen based on design score, best builder will be chosen according to combination of design and price score by the owner

Detail design performed by the best builder

Owner’s Design Consulting Committee’s deliberation of appropriateness of detail design ⇒ start construction

Figure 6-3: Processes of a Korean Design-Build project
**Alternate Design Bid process** (over 30 bill Won)

1. **Basic Consideration, and Feasibility study performed by the owner**
2. **Schematic design performed by the owner**: Basic format of facility, estimated construction cost, criteria for detail design, reflection of relevant parties’ opinions, and so on ⇒ **Detail Design** Performed by the owner including geotechnical investigation, and value engineering
3. **The Central Construction Deliberation Committee’s determination of if Alternate Design Bid will be used based on the basic plan**
4. **Owner’s Design Consulting Committee’s deliberation of Alternate/original design Design: Feasibility, Constructability, Maintenance, Safety, Sustainability ⇒ Design Score**
5. **If alternate design costs less than original design? & alternate work costs less than owner’s estimated cost?**
   - Yes ⇒ Among Six alternative/original bids having been chosen based on design score, best builder will be chosen according to combination of design and price score by the owner ⇒ **start construction**
   - No ⇒ **Discard the alternate design bid**

*Figure 6-4: Processes of a Korean Alternate Design Bid project*
6.3 Recommendations mainly regarding the TPB based on schematic design

This project delivery system gives the general contractor nearly the greatest discretion to participate in design because a bidder submits a method for improving project performance, such as reduction of cost/duration/life cycle cost (the 98th provision of the Enforcement Decree of the Act on Contracts to Which the State is a Party). Even though the DB/ADB allows a general contractor to produce a design, the design evaluation criteria are too restrictive compared to those of the TPB based on schematic design. Thus, this project delivery system allows the project team to implement Lean Construction with more flexibility than the DBB, the DB or the ADB. For example, a general contractor can collaborate with the architect and the specialty contractors in his/her consortium to make a proposal so that it contains many Lean concepts such as how to integrate the product and process design, how to maximize values of the schematic design through Value Stream Analysis, and how to increase the plan reliability of the project. There is no specific regulation restricting such implementations and their efforts to implement Lean concept can be evaluated as an important bid feature.

The selected bidder based on the proposal is responsible for both the detailed design and the construction (the 105th provision of the Enforcement Decree of the Act on Contracts to Which the State is a Party) so that they can continue implementing Lean Construction under a perfectly integrated condition. Of course, the DB, the ADB, and the Technical Competition (TC) also assign a selected contractor to do both the detailed design and the construction, but there are regulations restricting complete implementation of Lean Construction. For example, the DB requires a bidder to suggest a schematic design of a project and it selects the constructor based on the schematic design. The problem is the evaluation criteria of the schematic design, which investigates all aspects of the design including technical/economical feasibility, constructability, safety/maintenance plan and sustainability (the 26th provision of the Regulation for Operation of Construction Technology Development and Management). This scoring incentivizes bidders to make the most beautiful design in view of scoring, not to make the most feasible and innovative design for the best project performance. The result of the biased purpose is to produce change orders similar to or worse than those of the DBB projects as we saw in the analysis in the page 110 of section 5.5.1.5. The ADB also has the same problem because the bid evaluation criteria are the same as those of the DB. The TC, in fact, has a more room for the selected general contractor to implement Lean Construction than TPB based on schematic design. However, the TC is used only under the restricted conditions, which were discussed in the section 6.7 below.

In spite of this flexibility of the TPB based on schematic design, the 42nd provision of the Enforcement Decree of the Act on Contracts to which the State is a Party (EDACSP) says that DBB with an investigation of capability to build should be normally used. The construction industry is urged to make the TPB based on schematic design the most prevalent project delivery system as stated in [3]-[B] of Table 6-1. However, the research findings in the Ch 5 do not support directly this fact and the recommendation. This recommendation is made by intuition based on a review on those existing Korean regulations.

Because bid evaluation of the TPB based on schematic design is left to the owners’ discretion (the 102nd provision of the EDACSP), it is recommended that a guide line be inserted in the relevant government directives for easier implementation of Lean Construction in accordance with [3]-[A] of Table 6-1. However, the research findings in the Ch 5 do not support directly this fact and the recommendation. This recommendation is made by intuition based on a review on those existing Korean regulations.
According to the 97th provision of the EDACSP, an owner can use this project delivery system only when his/her project involves a symbolic representation, a commemorative feature, an artistic value or highly difficult technology. These conditions are not clear, which make the owners reluctant to use this system, as stated in [3]-[c] of Table 6-1. To increase usage of this system, it is recommended that directives be modified to guide owners to select this system based on the actual characteristics of their projects such as level of difficulty or complexity, as stated in [3]-[C] of Table 6-1. However, the research findings in the Ch 5 do not support directly this fact and the recommendation. This recommendation is made by intuition based on a review on those existing Korean regulations.

6.4 Recommendations mainly to the TPB based on detailed design

The purpose of this project delivery system is not clear. If an owner makes a detailed design of his/her project, determines which part of the design needs the bidders’ creativity, and uses the TPB based on the detailed design for promoting that creativity, then it would be understandable. However, this case should logically be dealt with using the Alternate Design Bid. It is recommended that the relevant regulation provide a more reasonable rationale about when the owners should use this system this project instead of the TBD based on schematic design, otherwise it is recommended that this project delivery system be eliminated, as shown in [4]-[B], Table 6-1. However, the research findings in the Ch 5 do not support directly this fact and the recommendation. This recommendation is made by intuition based on a review on those existing Korean regulations.

This project delivery system allows a ‘change order’ increasing project cost only when there is an unavoidable natural condition or the owner requests it (the 91th provision of the EDACSP), which means basically this project delivery system does not allow any regular change order. However, on the other side, the 103rd provision of EDACSP forces the bidders to submit detailed quantities and prices of materials. This is confusing, as detailed quantities, determined before construction, are likely to change as a result of using ‘Lean Construction’, but this project delivery system does not allow any regular ‘change order’ requested by a general contractor. That is the current state what the [c] in the [4] of Table 6-1 shows. Thus, it is recommended that the request for submission of detailed quantities be deleted, as stated in [4]-[C] of Table 6-1.

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58 Thus, the plan reliability is measured by the weekly plan’s success not by the master plan at the beginning. How to make each weekly plan successful is the key in the ‘Lean Construction’ production control.
6.5 Recommendations regarding mainly DB and ADB

According to the MCCI (2009), the average bid-award price was 68.6% of the average estimated price of the ‘Design-Bid-Build (DBB) projects with competitive bidding based on the least price’ but the percentage of the average bid-award price in the average estimated price of the Design-Build/Alternate Design-Bid (DB/ADB) projects was 92.1% in 2008. This big difference can be acceptable only if there is much less chance of change orders in the DB/ADB projects than the DBB projects. It is reasonable to expect that change orders in the DB/ADB projects are much less frequent than those of Design-Bid-Build (DBB) projects because the general contractors of the DB/ADB projects were responsible for the designs and could have already included contingency in the bid price.

However, this possibility did not stand up to statistical analysis. An unequal Welch T-test\(^{59}\) of the cost reduction ratio between the DB/ADB and the DBB projects found no significant difference in cost reduction. (Table 6-2 is the summary of the unequal Welch T-test.) Of course, the data sets were different. The data in MCCI (2009) were from projects in 2008 while the data analyzed in this research was from projects in the years from 2004 to 2009. Even considering the time difference, this result raises the question why the DB/ADB should exist if it cannot prevent ‘change order’ in spite of higher contractual prices than the DBB form. In addition, the 91st provision of the EDACSP states that there should not be any ‘change order’ increasing the contractual cost in a DB/ADB project unless the owner orders it or there is unavoidable natural catastrophe. It is not easy to understand that the DB/ADB projects underwent change orders with a similar degree to the DBB projects in spite of the legal protection.

Judging from the average bid awarding price of DB/ADB projects more than 90% of the estimated price, it is suspected that there might not be sufficient competitions among bidders. Too small a number of competitors could involve serious problems such as bid rigging. Indeed, this kind of suspicion has been supported by numerous news articles. For example, the Citizens’ Coalition for Economic Justice filed a complaint to the ‘fair trade commission of Korea’ in Nov. 2009 alleging that 101 big construction companies did rigged bids.\(^{60}\) Some members of the National Assembly tried to file a complaint with a prosecution to investigate if the relevant minister participated in bid riggings of a specific public project Oct. 2010.\(^{61}\) A member of the national assembly held a press conference at which he claimed that several biggest construction companies had done bid riggings to share a public construction project with higher contractual prices beyond common sense.\(^{62}\) There have been a lot of rumors about the DB/ADB projects’ bid rigging in the nation’s industry.

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\(^{59}\) The ‘sdtest’ in STATA showed that the two groups had significantly different within-group variance

\(^{60}\) http://blog.daum.net/qkkkk66/12346425

\(^{61}\) http://www.hani.co.kr/arti/economy/economy_general/445598.html

\(^{62}\) http://www.pressian.com/article/article.asp?article_num=60091108131310&section=01
Table 6-2: T-test of cost reduction ratio between the DB/ADB and the DBB

**General features** are in the right below

<table>
<thead>
<tr>
<th>Group</th>
<th>Observation</th>
<th>Mean</th>
<th>Standard Error (SE)</th>
<th>Standard Deviation (SD)</th>
<th>95% of confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>DB/ADB</td>
<td>46</td>
<td>-7.59</td>
<td>1.51</td>
<td>10.24</td>
<td>-10.63 - -4.55</td>
</tr>
<tr>
<td>DBB</td>
<td>40</td>
<td>-11.71</td>
<td>2.43</td>
<td>15.34</td>
<td>-16.61 - -6.80</td>
</tr>
<tr>
<td>Combined</td>
<td>86</td>
<td>-9.51</td>
<td>1.40</td>
<td>12.95</td>
<td>-12.28 - -6.73</td>
</tr>
</tbody>
</table>

**The variance Ratio test** (sdtest) is in the right below

<table>
<thead>
<tr>
<th>Ratio= SD(DB/ADB)/SD(DBB)</th>
<th>Ratio (f) =0.45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null hypothesis: Ratio = 1</td>
<td>Degree of Freedom = 45, 39</td>
</tr>
<tr>
<td>Alternative hypothesis: Ratio &lt; 1</td>
<td>Alternative hypothesis: Ratio!=1</td>
</tr>
<tr>
<td>Probability (F&lt;f) =0.0047, we can take this alternative hypothesis because the probability is less than 0.05</td>
<td>2*Probability (F&lt;f) = 0.0094, we can take this alternative hypothesis because the probability is less than 0.05</td>
</tr>
<tr>
<td>Probability (F&gt;f)=0.9953, we cannot take this alternative hypothesis.</td>
<td>Probability (F&gt;f)=0.9953, we cannot take this alternative hypothesis.</td>
</tr>
</tbody>
</table>

**The unequal Welch T-test** is in the right below

<table>
<thead>
<tr>
<th>Difference=Mean (DB/ADB)-Mean (DBB)</th>
<th>Difference (t) =1.44</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null hypothesis: t=0</td>
<td>Welch’s degree of freedom = 67.77</td>
</tr>
<tr>
<td>Alternative hypothesis: t&lt;0</td>
<td>Alternative hypothesis: t!=0</td>
</tr>
<tr>
<td>Probability (T&lt;t) = 0.92, we cannot take this alternative hypothesis.</td>
<td>Probability (</td>
</tr>
<tr>
<td>Probability (T&gt;t) = 0.077, we cannot take this alternative hypothesis.</td>
<td>Probability (T&gt;t) = 0.077, we cannot take this alternative hypothesis.</td>
</tr>
</tbody>
</table>

The underlying cause for the concern in the right above may be too high barriers for small companies to participate in the bids for DB/ADB projects. There have been many supporting articles. For example, MCCI (2009) pointed out that lobbying the members of the ‘Central Construction Technology Deliberation Committee (CCTDC)’ illegally and lacking clearness in the bid evaluation had been dominant in the Korean DB/ADB projects to a high degree. A major newspaper reported on Oct.13, 2010 that major construction companies having participated in the bid for a DB/ADB project persistently lobby the relevant personnel lest they should waste the money, up to several billion Korean won, having been spent in making the schematic designs, the main bid documents. Another news story showed a real example in which a sub contractor hired by a major construction company spent 0.25 billion won on illegal lobbying for a 30 billion Korean won subcontract. There are many other such examples showing major contractors’ lobbying for award of DB/ADB projects. The illegal and expensive lobby is one of the high barriers that challenge small construction companies.

The other barrier is the highly expensive schematic design that prevents small companies from participating in bids for DB/ADB projects. If a contractor wants to participate in a bid for a DB/ADB project, he/she must spend several billion Korean won to make the schematic design.

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Those two aforementioned barriers are why most of the small construction companies cannot participate in DB/ADB projects’ bids and why bid rigging can happen among a small number of the biggest construction companies capable of all the lobbies and the expensive schematic designs. These diagnoses are the current state that the [5]-[a] of Table 6-1 describe.

In conclusion, it is recommended that the schematic design format be simplified so that qualified companies can participate in bidding and that clear bid evaluation criteria be developed, such as concrete records of performance on past similar projects, so that construction companies are not incentivized to do illegal lobbying/make unrealistically beautiful schematic design, but rather to focus on enhancing current project performance. These are the future state suggested in [5]-[A] of Table 6-1.

The DB/ADB projects’ bid evaluation is mainly based on the technical score of the schematic design, which is determined by the Central Construction Technology Deliberation Committee (CCTDC) or a Design Consulting Committee (DCC). The CCDTC and the DCC\(^{64}\) make their evaluation according to the framework provided by Table 6-3 (The 26\(^{th}\) provision of ‘the regulation for operation of construction technology development and management’). The problem with the table is its lack of clarity and realism. It tries to deal with almost every aspect of a design, driving bidders to produce complicated and expensive schematic designs in an attempt to meet the criteria. In addition, it is not practically possible for the CCTDC or the DCCs to evaluate all the items. That is the current state that the [c] in the [5] of Table 6-1. Thus, as is stated in [C]-[5], Table 6-1, it is recommended that the evaluation criteria be reduced and simplified so that the evaluation is more effective.

Table 6-3: The evaluation criteria of the schematic design of the DB/ADB projects

<table>
<thead>
<tr>
<th>Item of Evaluation</th>
<th>Detail of Evaluation Item</th>
<th>Portion of scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan feasibility</td>
<td>Appropriateness of investigation before design, appropriateness of design criteria selection, appropriateness of facility construction schedule, and appropriateness of surveying</td>
<td>20-30</td>
</tr>
<tr>
<td></td>
<td>Appropriateness of selected facility, appropriateness of applied construction methods, appropriateness of temporary facility works, appropriateness of additional facilities/safety facilities, appropriateness of process planning/construction scheduling/quality control</td>
<td>20-30</td>
</tr>
<tr>
<td>Maintenance plan</td>
<td>Appropriateness of maintenance plan, easiness of maintenance plan, appropriateness of preventive plan of disasters,</td>
<td>10-20</td>
</tr>
<tr>
<td>Safety</td>
<td>Appropriateness of plan arranging safety facilities, reviewing foundation stability/reinforcement, appropriateness of structural and sectional design, provision of accidents/disasters,</td>
<td>10-20</td>
</tr>
<tr>
<td>Economic feasibility</td>
<td>Benefit-cost analysis, appropriateness of maintenance cost, evaluation of new technology</td>
<td>10-20</td>
</tr>
<tr>
<td>Environmental sustainability</td>
<td>Reviewing eco friendliness, reviewing post environmental impact assessment, harmony with circumstances</td>
<td>5-10</td>
</tr>
<tr>
<td>Others</td>
<td>Reviewing fast track strategy (if it is a purpose of the project), application of new technology/new construction process (if needed), others needed</td>
<td>5-10</td>
</tr>
</tbody>
</table>

\(^{64}\) Every government agency can have its own DCC according to the 21\(^{st}\) provision of the enforcement decree of the Construction Technology Control Act.
6.6 Recommendations mainly to ADB

Current regulation allows owners to use Alternate Design-Bid only after making the detail design of their project (the 80th provision of the EDCSP). The implausible assumption here is that the detailed design made by an owner is not good enough for the project. If there had been a defect in the detailed design, why would the owner have not corrected the defect before the completion of the detailed design? In common sense, let alone the ‘Set Based Design’ theory, this obligatory procedure, in which first a detailed design was made and an alternate design is made later, very probably produces waste in the design process. That is the current state shown in [6]-[a] of Table 6-1.

I assert that the timing to use this ADB system should be right after the completion of a schematic design. At this time, the owner could know which parts needs the bidders’ creativity and whether the creativity can be achieved by a form of competitive bidding. That is the future state shown in [6]-[A], Table 6-1. This recommendation is supported by the aforementioned argument, not by the research findings in Chapter 5 directly.

According to the 79th provision of the EDCSP, an alternate design should have both a project cost and a project duration less than or equal to those of the original design. This is the minimum requirement to use this project delivery system. After meeting these two conditions, the alternate design should show new technology implementation, cost/duration reduction with functionality equal to or greater than that of the original design or less life cycle cost. Judging from this, owners do not seem to understand how to innovate their project until completion of the detailed design. Without clear understanding of their projects about performance improvement, the owner group cannot determine which alternate design is preferable. In fact, the criteria in Table 6-3 are used in ADB projects as well as in DB projects. Consequently, ADB has the same bid evaluation problem as discussed regarding DB in section 6.5. It is recommended that owners determine which parts need bidders’ creativity before the completion of the schematic design of their project so that they have the ADB bidder to design the part in detail, as proposed in [6]-[B] of Table 6-1. This recommendation is supported by the aforementioned argument, not by the research findings in Chapter 5 directly.

Recommendations [6]-[A] and [6]-[B] of Table 6-1 are not unusual outside of Korea. Some government agencies in the USA already adopt similar strategies. For example, Missouri Department of Transportation (MODOT) used Alternate Technical Concept (ATC), in which MODOT allowed prequalified contractors to submit ATCs confidentially while the design is processed and allowed them to bid at a certain point along with other contractors that had not submitted an ATC before design completion (MODOT, 2010). MODOT’s point is that the bidders’ creativity is introduced before the design is completed while Korean method allows bidders’ input only after the original detailed design has been completed by the owner. Another example is the project on Highway 171 performed by the Louisiana Department of Transportation and Development (LADOTD). This project used A (cost) +B (time) +C (future rehabilitation cost and user delay cost) type bid, which allowed a bidder to suggest different pavement material types or design to reduce the total amount of the bid price, the sum of A, B, and C cost. (Temple et al., 2004). Another important point here is that the owner identified important characteristics (in this case, the life cycle cost, shown as the future rehabilitation cost and user delay cost) of the project and let the contractor design to optimize accordingly.
6.7 Recommendations mainly to ‘Technical Competition’

Technical Competition provides greater opportunity to implement ‘Lean Construction’ than ‘Technical Proposal Bid based on schematic design’ because a general contractor can participate in a project before the completion of the schematic design. However, the use of this system has four severe restrictions (the 53rd provision of the enforcement decree of the Construction Technology Control Act). The first restriction is that any project, whose presumed price is more than 30 billion Korean won and which is comprised of various construction works, cannot take this method as the project delivery system (the 79th provision of the Act on Contracts to which the State is a Party); the second is that any project, whose presumed price is less than 30 billion Korean won and whose owner decides it is advantageous to deliver the project though Design-Build or Alternate Design-Bid, cannot take this method as the project delivery method; the third is that more than 50% of total project cost should be used in delivering the parts, to which the target technology is applied directly; and the fourth is that anyone who does not possess the technology described in the bid that he/she submits cannot be awarded the project. That is what 7-[b] of Table 6-1 describes as the current state. Thus, it is recommended that these strict conditions be relaxed or changed to more reasonable conditions such as level of difficulty/complexity of a project, as stated in [7]-[A], Table 6-1. This recommendation is supported by the aforementioned argument, not by the research findings in Chapter 5 directly. For further information, see Figure 6-5, describes the overall processes of this project delivery system.
Technical competition (creativity/new technology)

Basic Consideration, Feasibility study, and Basic plan of project execution performed by the owner

The Central Construction Deliberation Committee’s determination of if Technical competition will be used based on the basic plan

Invitation to bid: project name, owner (government agency), main contents of project, total project budget with annual budget plan, and starting time

Evaluation of techniques submitted: bidder’s technical competence, experience in similar filed, project execution plan, and credit rating

Detailed design and construction by the best bidder: Schematic design can be omitted. This is for very technical projects

Restriction: 1. Target of Design build and Alternate bid are excluded; 2. New technique is responsible for more than 50% of total project cost; 3. The constructor should have the original technique

Pre-determined Bid Evaluation criteria made by the owner

Figure 6-5: Processes of a Korean Technical Competition project
6.8 Recommendations mainly to the Design-Bid-Build (DBB) projects.

The 64th provision of the Enforcement Decree of the Construction Technology Control Act makes it mandatory for owners to do ‘Value Engineering (VE)’ of the detailed design of their projects if the presumed cost of the project is more than 10 billion Korean won. This has the same defect as does ‘Alternate Design Bid’, requiring bidders to produce alternate designs after owners have finished the original detailed design. If they can modify a design to add more value, why did they not do that initially? That is an example of the negative iteration introduced with ‘Set Based Design (SBD)’ in section 3.2.3.

According to the public announcement, the ‘guideline for investigation of design’s feasibility’ promulgated in 2010 by the ministry of Land, Transport and Marine affairs, a VE should be done by a third party excluding the architect who has made the original design. It is recommended that this mandatory provision forcing the owners to do VE regardless of the characteristics of his/her design be deleted. If there is any room to improve, that should be done by the modified ‘Alternate Design Bid’ as recommended in section 6.7, and stated in [8]-[A] of Table 6-1. This recommendation is supported by the aforementioned argument, not by the research findings in Chapter 5 directly. For further information, see Figure 6-6, which shows the overall processes of a DBB project.
Basic Consideration, Feasibility study, and Basic Plan for construction: presumed cost, limit of cost increase, duration, annual budget/construction plan, priority of facility construction, maintenance/environment protection plan, and son

Schematic and Detailed design, then VE (mandatory)

DBB With investigation whether the minimum price is possible (type 1)

Yes

Over 10 billion Korean Won?

No

DBB With investigation of capacity to build (type 2)

Invitation to bid and prequalification (mandatory): past experience, technique, finance, credit rating, appropriate size of construction, etc.

Investigation of capacity to build including sincerity, past performance, bidding price based on incidental estimated price, etc., from the least price bidder

Select the best builder and start construction

Invitation to bid and prequalification (optional)

Investigation whether the least price is possible from the least price bidder considering total/each work’s and supply cost as well

Figure 6-6: Processes of a Korean Design Bid Build project
References


APPENDIX

A.1. Limb 3 strategy
Limb 1 is the direct project cost and overhead, Limb 2 (fees) is corporate overhead and profit, and Limb 3 is the predetermined pain share and gain share arrangement. Main decisions are made by the Project alliance board unanimously. At least, non owner participants (NOP) receive their direct cost (limb 1) and the burden which occurs after limb 2 is exhausted is up to the owner. As for distributing Limb 3, the difference between Limb 1 and target cost, Key Performance Indicator (KPI) is considered. If KPI is excellent, all the cost saving can be NOP’s, which is more than split of limb 3 fee. Otherwise, the opposite situation will occur.

A.2. Original version of the survey instrument
This is the original form before data gathering, which is made for measuring Design-Build projects. The respondent should be an owner, unless otherwise indicated.

<Basic facts>

1) What was the name of the project? _________
2) When was the project finished? ___________
3) What was the total number of square meters or feet of construction of the project?___________
4) What was the total number of paid man hours of construction of the project? _____________
5) What was the contractual or agreed price of construction of the project? $ ____________
6) What was the contractual or agreed price of design of the project? $ ____________
7) What was the contractual or agreed duration of construction of the project? _____ Years and _____ Months
8) What was the contractual or agreed duration of design of the project? _____ Years and _____ Months
9) What was the actual cost of the construction part of the project when it was finished? $ ________
10) What was the actual cost of the design part of the project when it was finished? $ ________
11) What was the actual duration of the construction part of the project upon completion? _____ Years and _____ months
12) What was the actual duration of the design part of the project upon completion? _____ Years and _____ months
13) How many accidents, which caused human injuries, were reported during construction? ____________
14) What was the total number of man hours used in the remediation of defects during the first year after handing over? _________

<Part I>
1) Please rank the following items according to the importance in selecting the main contractor? (the most important thing would be 1, and the least one would be 7)
   a) Price_____,
   b) Duration_______,
   c) Performance of past similar projects_____,
   d) Appropriateness of Conceptual design_____,
   e) Technological ability______
   f) Understanding of the project______,
   g) others____________________
      (Please list the others) ________________________

2) If you considered performance of past similar projects in selecting the main contractor, which items did you consider? Please mark all.
   a) Construction within promised price _______
   b) Construction within promised duration_______
   c) Less defects remediation__________
   d) Fewer accidents reported__________
   e) The total price compared to similar projects________
   f) The total duration compared to similar projects_______

3) Did the main contractor investigate the current similar projects before the contractual cost was determined?
   Yes______, No______, if Yes, go to 4); if No, go to 7)

4) Did the main contractor participate in making the expected cost of the project?
   Yes______, No______, if Yes, go to 5); if No, go to 7)

5) (This question is for the main contractor) what percentage of all specialty contractors participated in making the expected cost of the project? please check one
   a) 0%__ b) 0 to 25%__ c) 25% to 50%__ d) 50% to 75%__ e) 75% to 100%, go to 6)

6) (This question is for the main Contractor) What percentage of all specialty contractors participated in the design of the project? Please, check the nearest one.
   a) 0%__ b) 0 to 25%__ c) 25% to 50%__ d) 50% to 75%__ e) 75% to 100%, go to 8).

7) (This question is for the main Contractor) Who produced the expected cost? Please select all the relevant ones, go to 8).
   a) Owner__ b) owner’s architect__ c) others, please specify them______

8) Did you set the target contractual cost and duration of the project, which were less than or equal to the expected cost and duration of the project? Yes____, No_____. If yes go to 9); If No go to 11)

9) Did the main contractor participate in setting the target contractual cost and duration?
   Yes______, No______. If yes go to 10); If No, go to 11)

10) (This is for the main contractor) what percentage of all specialty contractors participate in setting target cost and duration of the project? Please check the nearest one.
    a) 0%__ b) 0 to 25%__ c) 25% to 50%__ d) 50% to 75%__ e) 75% to 100%, Go to 11)

11) Did you set principles to distribute the difference between the actual cost spent and the target contractual cost among all participants? Yes____, No_____. If Yes, go to 12); if No, go to 15)

12) Did you set principles to distribute the fiscal effect caused by the difference between the actual duration spent and the target contractual duration among all participants? Yes____, No____. Go 13)
13) Did the main contractor participate in setting the principles? Yes____, No____. If Yes, go to 14); If No, go to 15)
14) What percentage of all specialty contractors participated in setting the principles? Please select the nearest one.
   a) 0__ b)0 to 25% c)25% to 50% d)50% to 75% e)75% to 100% Go to 15)
15) Was the performance of the project assessed and recorded into a data base after being completed? Yes____, No____. If yes, go to 16); if No, go to 17)
16) Is it a private database or is it open to the market? Yes____, No____. Go to 17)

<Part II-1>

17) (This is for the main contractor) Did the main contractor decompose the target cost and duration into each component of the project? Yes____, No____. If Yes, go to 18); If No, go to 19)
18) (This is for the main contractor) What percentage of all specialty contractors participated in decomposing the target cost and the target duration into each component of the project? Please select the nearest one.
   a) 0__ b) 0 to 25% c) 25% to 50% d) 50% to 75% e) 75% to 100% Go to 19)
19) (This is for the architect) Did each specialist of the design part consult other related specialist of design part when designing? Please select the nearest one.
   a) Never__ b) Rarely___ c) Sometimes___ d) Often__ e) Always__ Go to 20)
20) (This is for the architect) Did each specialist of the design part consult the main contractor when designing? Please select the nearest one.
   a) Never__ b) Rarely___ c) Sometimes___ d) Often__ e) Always__ Go to 21)
21) (This is for the architect) Did each specialist of design consult the related specialty contractors when designing? Please select the nearest one.
   a) Never__ b) Rarely___ c) Sometimes___ d) Often__ e) Always__ Go to 22)
22) (This is for the architect) Did each specialist review all possible alternatives of design at the same time? Please select the nearest one.
   a) Never__ b) Rarely___ c) Sometimes___ d) Often__ e) Always__ Go to 23)
23) (This is for the architect) Did each specialist eliminate the design alternatives, which could not pass the constraints including the target cost and duration, until it has only one alternative? Please select the nearest one.
   a) Never__ b) Rarely___ c) Sometimes___ d) Often__ e) Always__ Go to 24)

<Part II-2>

24) (This is for the main contractor) Did you design the process for delivering a component when the architect designed the component? Please select the nearest one.
   a) Never__ b) Rarely___ c) Sometimes___ d) Often__ e) Always__ Go to 25)
25) (This is for the main contractor) What percentage of specialty contractors participated in designing the process of the project?
   a) 0__ b) 0 to 25% c) 25% to 50% d) 50% to 75% e) 75% to 100% Go to 26)
26) (This is for the main contractor) Did you try to minimize the batch sizes of materials delivered between processes when designing processes?
   a) Never__ b) Rarely___ c) Sometimes___ d) Often__ e) Always__ Go to 27)
27) (This is for the main contractor) Did you try to standardize materials or processes as many as possible when designing processes?
   a) Never  b) Rarely  c) Sometimes  d) Often  e) Always  Go to 28)

28) (This is for the main contractor) Did they try to moving, deleting, or adding inventories (storages) to reduce waiting time of the materials in the inventories when designing processes?
   a) Never  b) Rarely  c) Sometimes  d) Often  e) Always  Go to 29)

29) (This is for the main contractor) Did they try to preassemble materials before installment of the materials as many as possible when designing processes?
   a) Never  b) Rarely  c) Sometimes  d) Often  e) Always  Go to 30)

<Part III>

30) (This is for the main contractor) For example, the phases in construction of office building can be preparation of the site, foundation, framing, exterior finishes, mechanical, insulation and air sealing, interior finishes, landscaping, and closing phases.
   Before entering construction of such a phase, what percentage of all handoffs between workers in the phase did you define including their sequences and durations? Please select the nearest one.
   a) 0  b) 0 to 25%  c) 25% to 50%  d) 50% to 75%  e) 75% to 100%  Go to 31)

31) (This is for the main contractor) What percentage of all specialty contractors related to the phase participated in defining the handoffs in the phase? Please select the nearest one.
   a) 0  b) 0 to 25%  c) 25% to 50%  d) 50% to 75%  e) 75% to 100%  Go to 32)

32) (This is for the main contractor) A master schedule defines phases’ duration and latest finish times. And it usually reflects the critical schedule of the owner. Phase scheduling is to define handoffs in a phase.
   Was a seriously problematic decision, made in the master schedule, modified through conversations among relevant participants when it was found in the phase scheduling?
   a) Never  b) Rarely  c) Sometimes  d) Often  e) Always  Go to 33)

33) (This is for the main contractor) Please check all, which a specialist, who was responsible for a work, investigated before executing the work. Go to 34)
   a) If prerequisite works were done
   b) If contractual approvals were done
   c) If the work was in the right sequence
   d) If the resource materials were enough
   e) If the duration of the work is enough
   f) If there was problem in fund
   g) If the climate and site condition were good
   h) If the labor and equipment were good

34) (This is for the main contractor) When did each specialist start the constraint analysis described in 33)? Please select the nearest one.
   a) Before 12 weeks  b) Before 8 to 12 weeks  c) Before 6 to 8 weeks  d) Before 1 to 6 weeks  e) others, please specify others  Go to 35)

35) (This is for the main contractor) What percentage of all workers did the constraint analysis described in 33)? Please select the nearest one.
   a) 0  b) 0 to 25%  c) 25% to 50%  d) 50% to 75%  e) 75% to 100%  Go to 36)
36) (This is for the main contractor) What percentage of all workers did pseudo works like experiments before executing the actual work? Please select the nearest one.
   a) 0__ b) 0 to 25%__ c) 25% to 50%__ d) 50% to 75%__ e) 75% to 100%__ Go to 37)

37) (This is for the main contractor) Was a seriously problematic decision, made in the phase schedule, modified through conversations among relevant participants when it was found in constraint analysis described in 33)? Please select the nearest one.
   a) Never__ b) Rarely___ c) Sometimes__ d) Often__ e) Always__ Go to 38)

38) (This is for the main contractor) What percentage of all workers investigated the readiness of the next workers in receiving the handoffs they produced before producing the handoffs?
   a) 0__ b) 0 to 25%__ c) 25% to 50%__ d) 50% to 75%__ e) 75% to 100%__ Go to 39)

39) (This is for the main contractor) What percentage of processes had their communication channels with their adjacent processes, the previous and the following ones? Please select the nearest one.
   a) 0__ b) 0 to 25%__ c) 25% to 50%__ d) 50% to 75%__ e) 75% to 100%__ Go to 40)

40) (This is for the main contractor) Was a seriously problematic decision, made in a constraint analysis of a work described in 31), modified through conversations among relevant participants when it was found right before (approximately before 1 week) the work’s execution? Please check the nearest one.
   a) Never__ b) Rarely___ c) Sometimes__ d) Often__ e) Always__ Go to 41)

41) (This is for the main contractor) What percentage of all causes of the past plans failed in being executed was removed before the next similar plans were executed? Please select the nearest one.
   a) 0__ b) 0 to 25%__ c) 25% to 50%__ d) 50% to 75%__ e) 75% to 100%__ Go to 42)

42) (This is for the main contractor) Did each worker investigate if the causes of the past plans’ failures had been removed? Please select the nearest one.
   a) Never__ b) Rarely___ c) Sometimes__ d) Often__ e) Always__ Go to 43)

<Part IV> : this part is only for Korean industry

43) Do you agree that a contractor will exaggerate the cost or time if the contractor makes the design of the project? Please select the nearest one.
   a) strongly agree___ b) agree___ c) intermediate ____ d) disagree____ e) strongly disagree____ Go to 44)

44) (This is for the main contractor) Do you agree that a specialty contractor exaggerate the cost or time if the specialty contractor participates in the design of the project? Please select the nearest one.
   a) Strongly agree___ b) agree___ c) intermediate ____ d) disagree_____ e) strongly disagree__. Go to 45)

45) (This is for the main contractor) Do you agree that an owner will demand more works if the design is not concrete or specific enough? Please select the nearest one.
   a) Strongly agree___ b) agree___ c) intermediate ____ d) disagree_____ e) strongly disagree__. Go to 46)

46) Do you agree that the current selecting method of Korean Construction Industry would harm the continuous improvement of the industry? Please select the nearest one.
   a) Strongly agree___ b) agree___ c) intermediate ____ d) disagree_____ e) strongly disagree____.
47) How big percentage of bidders, who participated in prequalification of the bid, passed the prequalification test? _______%

(This is for the main contractor) question asking centralized control about project scheduling.
A.3 Contents of the additional survey questioning constraint analysis

<The question asking the constraint analysis>

Of all specialty contractors, who participated in the construction of the project, what percentage did the constraint analysis described above? Please select the nearest one based on your experience on average.

[Korean version]

이 공사의 건설에 참여한 모든 전문 건설업자들 또는 하도급자들 중 몇 퍼센트나 앞에 기술된 많은 작업들의 제한 조건 분석을 하였습니까? 귀하의 경험에 기초하여 평균적으로 가장 적절한 답을 고르세요.

<The question asking about a first run study>

Of all specialty contractors, who participated in the construction of the project, what percentage did pseudo works like experiments before executing the actual work? The purpose of this pseudo works is for finding the constraints which you might have missed in the constraint analysis described in the above. Please select the nearest one based on your experience.

[Korean version]

이 공사의 건설에 참여한 모든 전문 건설업자들 또는 하도급자들 중 몇 퍼센트나 담당한 작업을 수행하기 전에 실험적인 의사 작업을 하였습니까? 이 의사 작업의 목적은 4번에 기술된 작업의 제한 조건 분석에서 혹시 생략될 수 있는 제한 조건을 찾아내기 위함입니다. 귀하의 경험에 기초하여 평균적으로 가장 적절한 답을 고르세요.

A.4. Interview for the first case on Oct. 25, 2010

① Interview with the contractor (Oct. 25, 2010)

<Question #1>

The production control of Lean Construction can be summarized to three components. The first directive is to locate a work on weekly work plan only when all constraints are removed, the second one is to release the work to the next worker only when the next production unit is ready to receive and the third one is to release the work as soon as possible if the next production units are ready so that there is no waiting time for the handoffs.

Do you believe this principle enhances the productivity? And do you think this principle was used in your project? If yes, how much was it used?

<Answer>

I totally agree. If the nature and overall constraints of a work had been defined before execution, first of all, we deleted all the constraints before locating it on execution plans. We have tried to
reduce waiting time of a work while considering the next production unit’s condition of receiving
the work. However, when I am saying about considering overall constraints, I am talking about
the real conditions that I had known from my experience as well as what the nominal text books
related to construction management indicated as constraints. Construction has great variability in
nature. There is a proverb in our field that you never know until you dig the earth. When we went
to the site with specific contractors, the unexpected conditions occurred very often. That is why
we need experience in defining overall constraints. Definition and removal of constraint and
reduction of waiting time were really helpful in this project. We felt it.

<Question #2>

According to your responses to the previous questions that I sent to you, the lower levels’
schedules often corrected the higher levels’ schedules if the lower schedules found the wrong
decisions made in the higher levels’ schedules. To my understanding, Korean society is really
hierarchical so that it is hard for a lower level’s decision maker to correct the decisions made by
the higher levels’ decision makers.

Did you understand the questions correctly? And do you think that a schedule can modify the
schedule immediately above the former schedule is desirable to increase overall productivity?

<Answer>

First of all, I need to explain the structure of our schedule. At the beginning, we made the overall
expected schedule, which is the biggest one and contains the important owner’s milestones. Then,
we made the annual schedules. The overall expected schedule and the annual schedules specify
the rough contents which should be specified in more detail by the schedules per work type (or
specific trade). The work type schedules are regenerated monthly or weekly as the executions
come closer.

Even though we use this logical order in making schedules, there are a lot of variables to
influence this logical order. Monthly and weekly schedules should always be able to cope with
changes. Without violation of the big flow in the overall expected/annual schedules, we
frequently changed monthly/weekly schedules. For example, ‘the raining season in summer’ and
‘the non working days in winter’ demand us to change the order of some works based on the
characteristics of the works such as whether they are the dry processes or the wet processes.

However, it was rare to change the overall expected schedule or the annual schedules according
to the monthly or the weekly scheduling. If there had been any modification of the overall
schedule or the annual schedule, it would have been due to the abrupt and additional requests
from the final customers. For example, the future residents of an apartment could influence the
owner of the apartment’s construction so that the contractor should insert more complicated
functionalities causing big change in base line schedules. But in my memories, there did not
seem to be a case in which the monthly or the weekly schedules corrected the overall expected
schedule or the annual schedules.

<Question #3>

Do you know what the contractual/approved price of this project including the owner-driven
change orders and the difference between the approved price and the actual cost of the project?
And do you know the government data base recording most projects’ contractual cost? I found
there is discrepancy between the construction cost specified in the data base and the actual cost
provided through my research
I don’t know the exact difference between the contractual cost and the actual cost at the completion of the project. I remember that the difference was negligible. Sometimes, we must do change orders caused by the unexpected requests from the final customers, who would use the construction facilities produced by the project, or the people who lived near the construction site. The other case of change order was done by Value engineering. But the Value Engineering (VE) was based on the current market analysis. The original design should be modified, if it cannot follow the current market trends, in order to draw customers. We tried to suggest VE whenever it was necessary.

Interview with the architect (Oct. 25, 2010)

According to your previous responses to the questions that I had sent to you, every designer participated in the design after the previous specialists had finished their works while each designer consulted every relevant specialist during its work. How could it be possible?

Hmm, I don’t think we did good communication. Yes, as I answered in the survey, we, the designers who were responsible for the architect design, had always been communicating with other engineers such as electrical or civil ones. However, that was also true that each of the design engineers started its job after the previous engineers had finished their jobs. To understand this, we need to talk about the structure of the contract for the design. According to the relevant regulations, the owner should make separate contracts between the Architect Company and Electrical Engineering Company for the design. Generally, we, the architect company, make subcontract with Civil Engineering Company and others such as Mechanical Engineering Company.

The procedure is this. At the beginning, we made the draft of design and sent it to each of other design companies. Then, they sent back the feedback to us. According to the feedback, we made the new version of the draft. Then, we sent it again to each of the companies. This loop was repeated until the final version.

According to your previous responses to the questions that I had sent to you, the cost of the design of this project was reduced by 50% from the original contractual price. Could you explain how you did it?

I didn’t remember if there was reduction in cost. Probably there was not. Usually, we finished designs on budget.

Interview for the second case on (Nov. 7, 2010)

Why was the project delayed so long? In addition, there was a severe cost overrun too. Was it
due to contractual problem?

<Answer>

There was a contractual problem. At the beginning, it was a long term continuous project, in which there was no guaranteed annual funding plan but only total amount of price. That time was harsh to us. Sometimes, even what we only got as an annual fund was much less than 10% of the contractual price promised by the owner. After a while, actually a few years passed, it was converted to a continuous price project, which guaranteed total amount of price as well as the annual funding plan. Due to the first unreasonable contract, the first completion date should be delayed as you saw.

<Question #2>

The production control of Lean Construction is comprised of three components. The first is to locate a work on weekly work plan only when all constraints are removed, the second is to execute the work for the next worker only when the next worker is ready to receive the handoff produced by the work and the third is to release the handoffs as soon as possible if the next worker are ready so that there is no waiting time for the handoffs.

Do you believe this principle enhances the productivity? Do you think this principle was applied to your project? If yes, did your project get successful result from the application of the principle?

<Answer>

That concept is really familiar to us. The project management program that we used for the project was a kind of application of that concept and it was developed by our company. In my private opinion, our program management program is more inclusive than Lean Construction. However, I cannot feel it is really innovatively helpful to increase project performance. We had to use it because our bosses ordered it. Anyway, to a certain degree, the program helped us to get better performance. I cannot deny it.

<Question #3>

According to your responses, your designers always or often consult other designers, general contractor, and specialty contractors in order to produce the design alternatives as many as possible while designing their parts. And they narrowed down the design alternatives as the constraint analysis progressed until they found out the best design. We call the strategy ‘Set Based Design’

Do you think the Set Based Design was really helpful to reduce reworks in the design process?

<Answer>

Compared to Design-Bid-Build projects, definitely, this project made designers more frequently consult relevant specialists. Theoretically, it should have reduced reworks. I agree with it to a certain degree but not much.

<Question #4>

Could you tell me the Frequency of using Open Account?

<Answer>

We used an absolute open account between general contractor and specialty contractors but the open account system did not include owner’s account.
<Question #5>
Do you know the contractual cost recorded by the web site operated by the Korean government agency? According to the Framework Act on the Construction Industry, every awarded general contractor should report the contractual cost within a month after the contract through the system. According to the web site, the contractual cost of this project is XXXXX.

<Answer>
I don’t know how you got the price. I don’t know the price.

A.6. Interview for the third case (Nov. 8, 2010)
Interview with the contractor

<Question #1>
Was this project a Turnkey (Design-Build) or a Design-Bid-Build project? Because many parts of the design seemed to be changed, I am not sure exactly what kind of this project is. You seemed to be freer in changing design than a typical Design-Bid-Build project. If it was a Design-Bid-Build project, did it use the minimum price bidding or the investigation of capability to build? And, definitely, it continued more than one year. Was it a long term continuous project or a continuous price project?

<Answer>
This is a typical Design-Bid-Build with minimum price bidding and a long term continuous price. Similar to other Expressway projects, the owner guarantees that a certain amount of money will be provided within a certain amount of time. I know the long term continuous projects other than Expressway projects do not have annual budget at the beginning. However, during the period, there can be serious uncertainty in funding. Actually, our interval underwent eight months delay compared to the contract. And cost overrun is up to about 86%. But cost overrun was mainly due to unexpected events. For example, some part of our interval came to pass a region containing the parks for the natural environment study, which requested us to change the bridge type from an iron bridge to Pre-Stressed Concrete Bridge. And weather condition was also a factor causing delay. We had to recover the separated soil from slope by heavy rainfall.

<Question #2>
In some government documents, this project seemed to innovate on the construction processes through Value Engineering so that I saw the actual reduction in cycle time. Were the construction cost and duration reduced compared to the contractual cost/duration? Or were they increased?

<Answer> I don’t know about the whole cost/duration change of the project. As for the interval that I worked, see my previous answer.

<Question #3>
According to your answers, the wrong decision made in a higher schedule was rarely corrected by the schedule right below the previous schedule. For example, if something is determined in the master schedule, it was rarely modified even though you found it wrong when you did a phase scheduling about it. Am I right?

<Answer>
This is not a normal project whose fund is stable. There was big uncertainty in funding for this project. We could not make progress of the project based on a predetermined budget plan. First, we made monthly or weekly plans of the project only based on the characteristics of the project without too serious consideration of the budget. If there was no money, we just invested our money then paid back the money later. Changing schedule based on the constraint analysis was too naïve for this project.

<Question #4>

According to your previous answers, there were no incentives about cost reduction or schedule reduction. However, you did a lot of Value Engineering to reduce cost or duration. For example, you changed the concrete AE admixture, used MSS form to reduce the construction duration in the rain season, used a detailed measurement of the angle change of the wall to use MSS form in more appropriate way, changed the high bridge construction method from the climbing form to the slip form and improve the camber management system. Why did you do it even though there were no incentives for that?

<Answer>

Value Engineering was not the matter between the owner and us. Value Engineering had already been determined between the owner and the architect. If we did the ‘Value Engineering,’ that was, in fact, a change order actually because we did it when we felt it was not possible for us to construct something according to the contractual design. We did change orders under the name of ‘Value Engineering’

<Question #5>

The basic principles of Lean Construction are 1) a work cannot be located on a weekly work plan unless all constraints of the work are removed, 2) a work cannot be executed unless the next worker is ready to take the handoff produced by the work and 3) a work should be executed as soon as the next worker is ready to receive the handoff produced by the work. Do you believe these principles help improve project performance? If yes, can you say to what degree these principles were applied to this project?

<Answer>

If we see only the principles, these are ideal. If everything could be done only based on the principles without disturbance, that situation will be ideal flow. However, the real world is definitely different from the ideal situation. We cannot always apply these principles on site. Even though there are some constraints remaining, we have to work what we have to do. If everything goes in principle, these principles will get good results. In the real world? Only principles are not enough.

<Question #6>

According to your previous answers, 25 to 50% of all specialty contractors participated in the process design. If we restricted the range of specialty contractors in the question to the main specialty contractors (the criterion, main, is totally up to you), to what extent will the percentage increase?

<Answer>

100%. That is natural. We always collaborated with all the main specialty contractors. They
always raise questions whenever they need

In another article published by the government, this project used ‘one table’, in which all the relevant specialists collaborated to solve the problems raised by any one. Do you think this was efficient to solve the problems?

It was effective to a certain degree but not too much. According to the principles operating the ‘COMS’, anybody could raise a problem that needed collaboration to be solve and the problems could be discussed in the ‘One table.’ In fact, there was limit in the ‘One table.’ For example, such a need as provide a convenient place for workers in hot summer days can be discussed in the ‘One table’ because it was simple. However, technical problems were rarely discussed. To solve the technical problems involved with the owner, we had to make formal reports and specialty contractors did not have the capability or the right to make such reports. Thus, the first discussion was done between the specialty contractors and us. After making the decision about the problem, our representative made the formal report acceptable to the owner’s representative. After that, the owner’s representative decided if he/she accepted our decision. Yes, this was not the form of the ‘one Table’ discussion. Of course, the owner of this project tried to collaborate better than the other owners of the projects that we had worked before. I just want to tell you the limit of the ‘One table’.

A.7. Interview with an anonymous contractor (Apr. 26, 2009)

“Suggestions of new methods/technologies for construction are not for reduction of construction cost. Instead, when there are problems in original designs in traditional design-bid-build projects, those suggestions are used to modify the problematic designs in order to finish out the projects within budgets/times. Actually, those are change orders not value engineering or anything called as similar ones. Even in these cases, there is no opportunity for the corrected design to demand more money. Usually, owners don’t want these cases to be processed under owner driven change orders because they don’t want to admit the mistakes they had done in original designs and they feel change orders are bothering them. Thus, contractors proactively do the change orders under the name of value engineering or suggestion of new technologies. Most problems come from the confictions between the specifications made by government agencies and the realities. The specifications could not be changed nor updated. For example, let assume that to fix a facility that the government specification requires to have more than three fixtures per a certain interval, this requirement was specified in the specification, but both the contractor and the owner did not recognize it. But we, the contractor, had known three fixtures are enough to fix the facility based on our experience so that we fixed it with three fixtures per the interval. Then, at some time after the fixture construction, the construction supervisor found the number of fixtures did not follow the government specification. Guess what happened, we had to remove or disjoint the all fixtures after destruction of the concrete, and reinstall all the fixtures again. Being reluctant to update the specification to meet the current situation and forcing the government rules without any reasonable negotiation are the main problems in government sector.”

205
A.8. Interview for the sixth case on Nov. 9th 2010

<Question #1>
Because this project is a Project Financing, in which the general contractor invested first his/her money first and would be paid back the investment as the revenues were generated from the project, I thought there could have been the general contractors participation in design in order for him/her to be guaranteed a certain level of profit. Am I right? If yes, were there main specialty contractors who participated in the design of this project?

<Answer>
You are right. The general contractor, we, participated in the design and, actually, we suggested some design alternatives that had been believed to reduce cost or time with the same functionality. This is because we could be relieved from the cost/time reduction when there would uncertainty in benefit/cost expectation. However, if there was a certain level of future-benefit expectation, we didn’t try to reduce cost or time to excess because our goal was to be paid back the construction cost not to make profit as many as possible. There were no specialty contractors that participated in design.

<Question #2>
Did the designer often consult the general contractor?

<Answer>
Of course, Yes.

<Question #3>
I ask again. When you participated in the design, did you get some opinion from the specialty contractor?

<Answer>
No, all specialty contractors were selected after design

<Question #4>
Did you participate in the feasibility study done before the design?

<Answer>
Yes.

<Question #5>
A feasibility study usually produces the expected cost. Was the expected cost less than the contractual cost of the project?

<Answer>
I don’t know why the two costs should be separated. In feasibility study, we negotiated the cost with the owner. As a result, we contracted.

<Question #6>
Did the designers decompose the contractual cost into the project’s components?

<Answer>
I don’t know. Just apply the general situation to this project

<Question #7>
Did the designers receive the advice from all relevant participants so that they produced and reviewed the design alternatives as many as possible at the same time?

<Answer>
What you said is a kind of traditional way in design. Any designer does design in the same way. Ok, if the ideal case is 100%, this project used it up to 70%.

<Question #8>
Did the Designers eliminate the design alternatives as they developed the constraint analysis in more detail?

<Answer>
Similar to the answer right above.

<Question #9>
According to your answer, there was no incentive but can we guess there is something similar because this project is delivered by the Project Financing in which the general contractor invests his/her own money first and is paid back as the revenue is generated from the completed project so that the general contractor tries to reduce unnecessary cost or time to cope with the future uncertainty.

<Answer>
There was no legally specified incentive. That is why I answered there were no incentives. However, as you pointed, we tried to save unnecessary money because there was uncertainty to a certain degree but if we had spent less money we would have had been paid back less. We didn’t need to save too much money.

<Question #10>
Did this project employ the open account among the owner, the general contractor and the specialty contractors? If yes, could you tell the degree of the open account if we set the perfect open account condition as 100 %.

<Answer>
Usually, a Project Financing project employs a company, which manages all the relevant financial flow. The management company maintained transparent account related to the project. I think this is an open account.

<Question #11>
Did you design product and process concurrently? If yes, could you tell me the degree if we set the ideal case as 100 %.

<Answer>
No, the product design and the process design were developed separately.

<Question #12>
According to your previous answers, none of the handoffs of a phase were defined before the phase. Is it true?

<Answer>
I think I misunderstood the question before. Approximately 75% of the handoffs of a phase were defined before the phase.

<Question #13>
What percentage of all the specialty contractors participated in the phase scheduling?

<Answer>
None of them participated in the schedule. Usually, after having finished the design, we made the schedule, according to which the specialty contractors were selected. Every Korean project is same as this. It might be different from the foreign projects, in which there are long term contract between the general contractor and the specialty contractors.

<Question #14>
Could you tell me the relations with the specialty contractors? Was it proactively collaborative or just following the contract?

<Answer>
We were in good relation. If there had been any problems, we would not have chosen them at the beginning.

<Question #15>
If you count only the main specialty contractors among the all of them based on their contribution to this project, what percentage of all does the main specialty contractors take?

<Answer>
Approximately 25%

<Question #16>
Lean Construction can be summarized to three components. The first is ‘never put a work on a weekly work plan unless all the constraints are removed. The second is ‘never put a work on a weekly work plan unless the next workers are ready to receive the handoffs produced by the work and the third is ‘execute a work instantly when the worker is ready to receive the handoffs produced by the work.’ Do you think these principles are effective in improving project performance? If yes, to what extent these principles were used in this project?

<Answer>
Those principles are what everybody knows and are natural to this industry but the problem is it is just the ideal different from the real world. Anyway, we should execute some works even though the next workers were not ready as buffers to cope with the future uncertainty. If we set 100% as an ideal case, this project might record 75%.
A.9. Measurement of contractors’ participation in design in the third phase

I made some conclusions about measuring contractors’ participation in design after some search and set the criteria to measure. In addition, I introduced some examples of the invitation to bid.

<Conclusion 1>

Common specialty contractors are Mechanical (or HVAC), Electrical, Plumbing, and Structural contractors. There are also civil works and concrete works but they can be works of general contractor. Thus, this research decided not to count them as kinds of specialty contractor’s jobs.

<Conclusion 2>

It is hard to define what Common specialty contractors are in residential building projects. There can be a limitless number of kinds in residential building. In addition, without the information for what the GC is responsible, it is very hard to determine whether a project had main specialty contractors participate in design. It might not be reasonable to determine which specialty contractors are main one for a kind of building project.

<Conclusion 3>

Commonly, Plant construction needs Mechanical, Electrical, Plumbing, Roofing, and Fire protection sub contractors. Even though there could be a limitless number of Kinds of plant, considering a plant is also a structure, they probably need similar specialty contractors to a certain degree.

<Criteria to measure>

First, as for building projects other than plant, if there is any one from Mechanical (M), Electrical (E), or Plumbing (P) specialty contractors, it receives 0.25, if there are other ones than M, E, and P, it will receive 0.1 per a specialty contractor.

Second, as for plant construction, if there is any one from Mechanical (M), Electrical (E), or Plumbing (P) specialty contractors, it receives 0.2, if there are other ones than M, E, and P, it will receive 0.15 per a specialty contractor because plant construction can focus on special equipment more than general building components.

And supplementary principle, an Integrated Project Delivery project’s score in contractors’ participation in design is 2.35, and its description included most kinds of the specialty contractors. Thus, if there is any answer that all specialty contractors participated in design, it will receive 2.35.

<Examples the 1st: Health Care Facility>

(1) The ‘Scripps Proton Therapy center’ in San Diego (CA), $200 Million Patient treatment facility, announced the selection of eight sub contractors on November 8th 2010: ① Surveying; ② Site work including grading, paving, site utilities, and site concrete; ③ Cast in place concrete; ④ Fire protection system; ⑤ Plumbing and mechanical system; ⑥ Electrical system; ⑦ Structural and steel materials fabrication; and ⑧ Fabricated metal
(2) The general contractor of the University of Florida’s Lake Nona research center in Lake Nona’s Medical City put two bids for the subcontractors on August 9th 2010. The first bid, a 5 million $’s package, included ① temporary power and lighting; ② site work; ③ paving and hardscape; ④ foundation; ⑤ concrete structure; ⑥ masonry; and ⑦ structural steel and elevators. And the second bid, a 25 million $’s package, included ① construction works remaining; ② Electrical; ③ Heating Ventilation Air Condition (HVAC); ④ Plumbing; ⑤ Fire protection; ⑥ Exterior skin components; and ⑦ Finishes and equipment.

(3) The general contractor of the San Francisco General Hospital Rebuild Project (CA) announced a bid, whose due date is February 11th 2011, for awarding the subcontractors including ① Miscellaneous Metals, Stairs and Railings, and Wired Rope assemblies; ② Roofing, Sheet Metals and Flashing; ③ Seismic Controls; ④ Case Work and Finishing Carpentry; ⑤ Openings; ⑥ Acoustical Ceilings; ⑦ Tiling; ⑧ Terrazzo; ⑨ structural steel and elevators; ⑩ Flooring; ⑪ Painting; ⑫ Signage; ⑬ Health care equipment; ⑭ Specialties; and ⑮ Food service equipments.

Example the 2nd: Residential Building

(1) The Joseph Housing Senior Building project announced the invitation to bid for selecting general contractor and Sub Contractors. The bid package included ① Security, safety and fencing; ② Site Furnishing; ③ Building and Site concrete; ④ Misc. Metal Fabrication; ⑤ Finish carpentry; ⑥ Fire stopping; ⑦ Joint Sealant; ⑧ Mirrors and Glazing; ⑨ Residential Appliances; ⑩ Off Load staging of Materials; ⑪ Temporary Power; ⑫ Temporary Ventilation/Dry out Heat and Generating Power; ⑬ Lay out and control; ⑭ Debris Disposal, recycle and waste management; ⑮ Building Envelope Inspection; and so on.

(2) The Charles Hospice House project announced an invitation to bid for awarding subcontractors including ① Painting; ② Kitchen cabinet; ③ Appliances; ④ Generators; ⑤ Elevator; ⑥ Medical interior design; ⑦ Drywall; ⑧ HVAC; ⑨ Electrical; ⑩ Roofing; ⑪ Insulation; ⑫ Plumbing; ⑬ Framing; ⑭ Concrete and Masonry; ⑮ Excavation; and so on.

(3) The general contractor of the mud creek WPCP project announced the invitation to bid to award subcontractors including ① Bio solid Facility Civil and Mechanical; ② Outfall pipe; ③ and Finish site work.

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<Example the 3rd: Plant Construction>

(1) The central utility plant of the National Bio and Agro Defense facility held a pre bid conference on Jan 19th 2011 for subcontractors including ① Concrete Utility Masonry; ② Structural steel; ③ Water proofing; ④ Metal wall panel; ⑤ Roofing; ⑥ Mechanical; ⑦ Electrical; ⑧ Flooring ⑨ Painting; ⑩ Gypsum wall assemblies; ⑪ Elevators; ⑫ Test and Balance; ⑬ Fire Suppression; ⑭ Underground Utilities; ⑮ Asphalt paving; and so on 

(2) The subcontractor package for the City of sugar land 9-MGD Surface Water Treatment Plant included ① Site Fencing; ② Finish grade, Sidewalks and Paving; ③ Landscaping and Irrigation; ④ HVAC and Plumbing; ⑤ Masonry ; ⑥ Structural steel and Misc. Metals; ⑦ Roofing; and ⑧ Fire protection Utilities

(3) The San Antonio Military Medical Center project announced invitation to bid. The project included Central Energy plant construction requesting subcontractors comprised of ① Paving and Site work; ② Fencing; ③ Landscaping; ④ Roofing; ⑤ Fire proofing; ⑥ Masonry; ⑦ Curtain wall, Baguettes, and Louvers; ⑧ Doors, Frames, and Hard Wares; ⑨ Overhead Doors; ⑩ Signage; ⑪ Specialties; and ⑫ Traveling cranes