# QUANTIFYING THE POTENTIAL BENEFITS OF AUTOMATED DATA ACQUISITION TECHNOLOGIES INTEGRATION IN CONSTRUCTION DATA MANAGEMENT BASED ON BAYESIAN BELIEF NETWORK ANALYSIS

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To my parents and wife for unconditional support and encouragement

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It is widely recognized that construction activities may be one of the most complex industrial activities. Due to the complexity of construction activities, vast amounts of data are generated from every construction project. The collection and analysis of generated construction data are significant for contractors to be able to track the schedule, duration, labor, materials, and costs of construction projects. Therefore, adequate data management is required for successful project delivery.

Recently, as the size of construction projects is getting bigger and more complicated, the improvement of data management methods is necessary in construction activities. In today's construction industry, use of IT (Information Technology) is being emphasized to support these needs. Specifically, systems using various automated DATs (Data Acquisition Technologies) such as Bar Code, GPS (Global Positioning System), PDA (Personal Digital Assistant), RFID (Radio Frequency Identification), and USN (Ubiquitous Sensor Network) are being developed to facilitate data collection on construction sites.

In typical construction practices, manual data collecting system often cause problems of delaying completion or overrun project costs. In general, inaccuracy and inefficiency of data management leads to these problems. The integration of automated DATs in construction data management enables the reduction of inaccuracies by increasing the efficiency in data acquisition on construction sites, and it ultimately results in productivity improvement. Automated DATs can now be employed in various construction activities. For example, GPS and wireless technique can be used in construction site management, or road construction; and RFID systems have great capacity to control and monitor construction materials. Many studies highlight the requirement of advanced DATs' utilization in construction industries enabling us to control time and cost for projects in an effort to meet the expected results.

Even though previous studies indicate that automated DATs have great benefits for construction data management and enhance project performance, the actual impact of integration of automated DATs on construction productivity has not been fully investigated. This study identified and quantified the potential of integration of DATs on construction site using Bayesian belief networks.

# CHAPTER 1
# INTRODUCTION

Typical construction processes require adequate project management to control their execution. As the construction industry grows and projects get more complicated, advanced project management practices need to be adapted and developed. For successful construction delivery, productivity enhancement, risk management, cost analysis, schedule management, and data management are regarded as crucial project management practices. Of these management practices, data management is, particularly, experiencing a quite advancement, with innovative development of construction information management systems.

Effective construction data management plays a significant role in recording and tracking all construction activities. Furthermore, collected data can be used to assess the status of the project and to take corrective actions if needed. In spite of the significance of data management in construction projects, manual or partially automated data collecting procedures are used in construction sites. Manual data management procedures are labor intensive, inaccurate, and error prone. The weaknesses in manual data management practices cause a decrease in construction productivity, cost overruns, and schedule delays. On the other hand, the automated data acquisition technologies (DATs) for construction data management provide benefits for productivity improvement, time saving, and efficiency for data collection on construction sites.

In practice, several of automated DATs such as Bar Code, Global Positioning System (GPS), Personal Digital Assistant (PDA), Radio Frequency Identification (RFID), 3D scanning, and USN (Ubiquitous Sensor Network) are used on construction sites, enabling contractors to track construction data. However, several limitations and

disadvantages for each DAT type prevent the development of automated data management. Each DAT has its own characteristic and it can be utilized in limited construction activities. In addition, the outputs from current DATs might not be interoperable between different information technology (IT) platforms. Another limitation of DATs is the installation costs and uncertainties of DATs applications. One of the disadvantages of DATs is that specialized expertise may be required to operate certain DAT applications, and excess data may cause additional processes to be needed. Another problem in utilizing automated DATs is that there is no evidence of reliable DAT systems in practice. Therefore, the characteristics of different automated DATs are needed to be evaluated and analyzed in order to enhance their capabilities and to overcome limitations, enabling the integration of DATs to be used in construction data management.

In addition, even though the significance of each automated DAT is emphasized by many researches and studies, the very limited studies have been just focused on comprehensive explorations of automated DAT utilization in the construction industry. In other words, previous studies about automated DATs are mainly focused on a specific DAT for use by just a certain work group such as materials management, quality management, and workers' schedule monitoring. Therefore, comprehensive analysis and perspective studies with comparison of DATs are required to advance the development of automated DATs in the construction industry.

In this study, the characteristics of each automated DAT are investigated with detailed literature reviews. Also, the advantages and disadvantages of each DAT are described in detail. Then, the need for integration of automated DATs in construction

sites will be analyzed, and the potential of integration of DATs for construction data management will be assessed using Bayesian belief network (BBN) analysis.

## Objective of the Study

Since information systems were developed and introduced to the construction industry, numerous efforts to apply state-of-the-art information technology to construction field have been made. As a result, various kinds of automated DATs are developed for construction projects. The use of automated DATs on construction sites provides efficient management practices for control of material, schedule, cost, and productivity. However, individual automated DATs currently used on construction sites have limitations and disadvantages. Furthermore, small contractors have a tendency to hesitate about utilizing DATs in their project because of installation cost and uncertainties about DATs' performance.

Based on these problems of automated DATs, this study aims to identify current automated DATs' development and trends in construction management through detailed literature reviews and surveys. Subsequently, the potential benefits of the integration of DATs are demonstrated in this study. In order to clarify the positive factors for DATs' integration on real construction sites, the potential benefits of DATs will be evaluated and quantified using Bayesian belief network (BBN) analysis. In addition, prospective approaches for DATs' integrations and direction of future study will be proposed in this study.

## Scope of the Study

One of the main purposes of this study, latest DATs' development status and current utilization trends are introduced with literature reviews and case studies. In order to provide the feasibility of current DATs' integration, limited representative DATs,

which are Barcode, GPS, PDA, RFID, 3D scanning, and USN (Ubiquitous Sensor Network), is proposed in this study.

Since the main objective of this study is to quantify the potential benefits of the integration of DATs for construction data management, some mechanical fundamentals and technical explanations are excluded from this study.

A survey for this study was distributed to Korean contractors because it is considered that Korean firms have a great tendency to use IT in construction projects in comparison with companies in other countries. The data generated from the survey and literature reviews will be used as variables through the Bayesian belief network analysis for this study.

## Overview of the Chapters

The present study will address the importance of integration of DATs in construction data management practices, and attempt to quantify the potential benefits of DATs' integration using Bayesian belief network analysis.

Chapter 2 presents a literature review about automated DATs in construction industry. The reviews include the overview of each automated DAT's characteristics and its performances. Also, the characteristics of Bayesian belief network analysis are presented in this section.

Chapter 3 describes the methodology of this study. The current data of automated DATs' use were collected by survey. In the survey, supplementary questionnaires were given to respondents in order to verify the current DATs' effects on construction activities. The procedure and theory of Bayesian belief network analysis is also discussed in this section.

Chapter 4 summarizes the results of this study, and outlines the data analysis from the Bayesian belief network. Furthermore, the comparison of potential benefits of automated DATs' integration in between real construction sites and this study is provided.

Chapter 5 provides the conclusions and recommendations based on the findings from this study. The discussion of the possible ramification for DATs' integration in real construction practices is highlighted in this section.

# CHAPTER 2
# LITERATURE REVIEW

## Introduction

This chapter discusses current and relevant automated DATs information and the characteristics of Bayesian belief network analysis. First, an overview of automated DATs and current use of each DAT's introduction is included in this section. Second, some examples of the integration of automated DATs and their potential benefits are highlighted. Lastly, the characteristics and methodology for Bayesian belief network analysis are summarized.

## Overview of Automated DATs

Automated DATs have rapidly evolved with the development of IT. As a result, the areas of automated DATs' utilizations are being expanded to the construction industry, and these can be applied to effective data management on construction projects. During the past few decades, the effort to manually acquire and manage construction data has been a major barrier to improving the effectiveness of construction management (Nasir et al. 2010; Seo et al. 2010). However, implementation of recent automated DATs in the construction industry can greatly improve the overall construction management processes by enabling automatic data collection.

There are several representative DATs currently used on construction project sites including Bar Codes, Global Positioning Systems (GPS), Personal Digital Assistants (PDA), Radio Frequency Identification (RFID), USN (Ubiquitous Sensor Network), and 3D scanning (Seo and Jung 2008).

Seo et al. (2010) classified the distribution of representative DATs' use based on the type of project management used on construction project sites (see Figure 2-1).

This distribution was generated by the analysis of the frequency of DATs' application from previous studies. As shown in Figure 2.1, RFID and GPS are mostly used for material and schedule management, respectively.

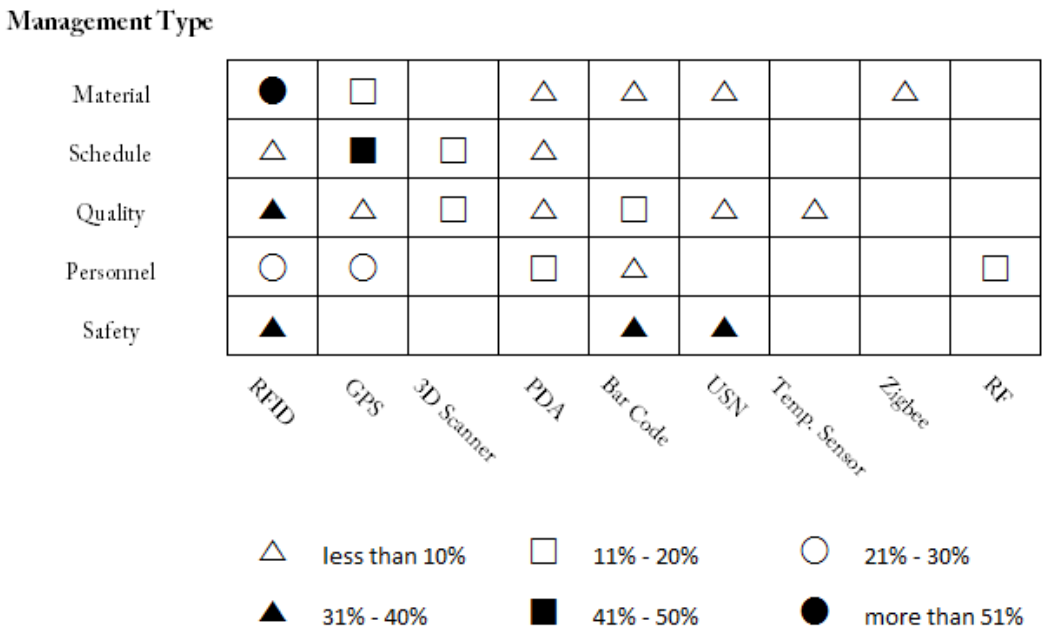


Figure 2-1. Distribution of automated DATs depending on management types in construction industry

When automated DATs are implemented on construction sites, labor-free and accurate construction data can be easily collected. Therefore, controlling or tracking the project status is more efficient, and it leads to productivity improvement.

However, each DAT has its limitation of suitability to track construction operations. Thus, the limitations of each DAT application and the integration of DATs to alleviate individual DAT's limitations should be studied and analyzed (El-Omari and Moselhi 2009).

**Bar Code and RFID (Radio Frequency Identification)**

Bar code applications were introduced to the construction industry in 1987 (Chen et al. 2002). During the past few years, bar code systems were mainly deployed in construction material handling and management practices because of the error-free and faster data entry characteristics of bar code system data (McCullouch and Lueprasert 1994). Even though the use of bar code system has been widely accepted in construction industry, several limitations and disadvantages of bar code use have emerged. The primary limitation is that the bar code label is easy to be damaged in the typically harsh construction environment (Bernold 1990). Durable barcode labels have been developed to protect them from the construction environment, but a manual scanning operation is still required to record information. This manual scanning procedure is regarded as one of the limitations of barcode use. Other disadvantages of barcode use are its short reading range and limited data storage capacity (Jang and Skibniewski 2007).

In order to overcome the limitations and disadvantages of barcode use, other individual DATs such as PDA, GPS, or wireless technology, have been integrated with barcode system. Especially, barcode system integrated with PDAs have been widely accepted for construction material management practices by enabling automatic data recording and transfer processing in relation to construction schedule (Cox et al. 2002 and Tserng et al. 2005). Figure 2-2 illustrates the conceptual implementation of barcode with PDA integration for automated material data management.

Recently, barcode system has been replaced by RFID DATs with the advent of RFID system. A typical RFID system is comprised of tags or transponders, and readers equipped with antenna and scanner, and it provides wireless communication between

tags and readers. These fundamental characteristics of RFID technology are capable of eliminating the limitations of barcode system. Unlike barcode technology, RFID systems have the ability to identify and track materials and equipment without manual recording operation. Furthermore, RFID systems have large storage capacity, wide reading range, durability, and high level of security (Lee et al. 2006). In general, 64 to 32,768 bytes of data can be saved onto an RFID tag (Jaselskis and El-misalami 2003).

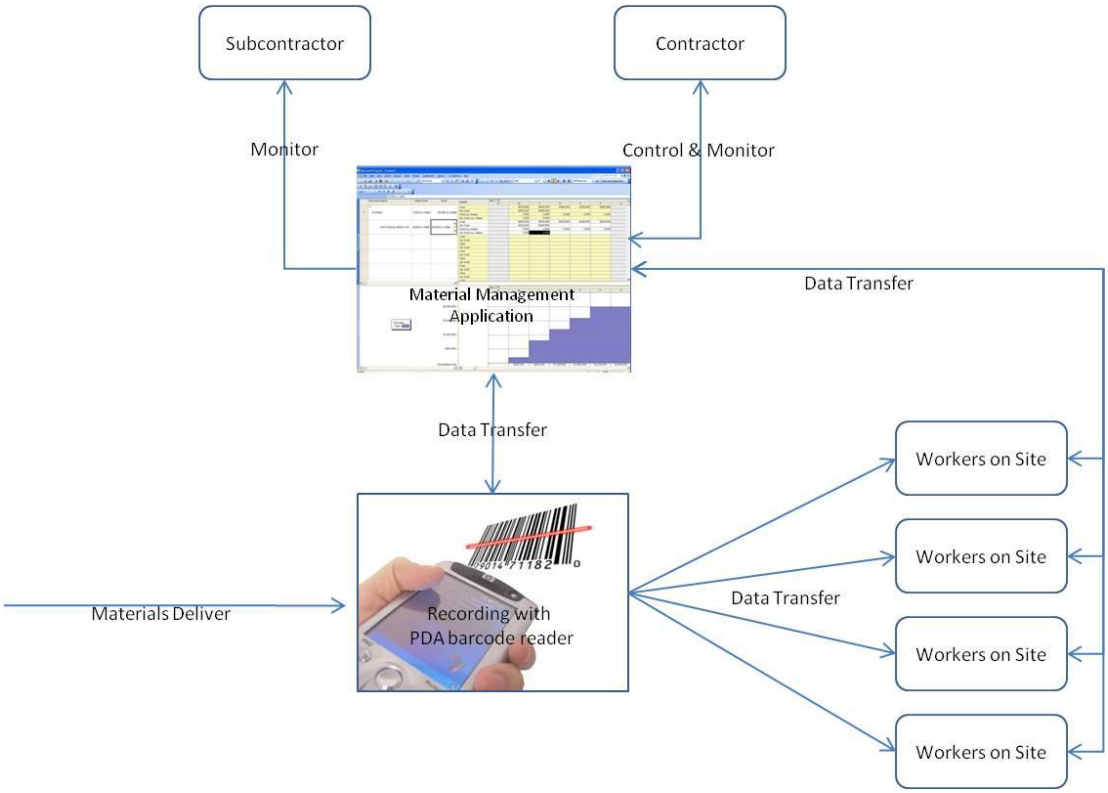


Figure 2-2. Conceptual implementation of barcode with PDA integration for material management on construction site

There are two types of RFID tags: active and passive. The tags use different frequencies depending on which countries they are used in. Table 2-1 summarizes the different characteristics between active and passive RFID tags and the different tag frequencies used by different countries.

With the rapid development of active RFID tags technology, their suitability for use in the construction industry is greatly advanced. As a result, the area of RFID DATs' application has been expanded to various construction fields such as risk management, waste management, material control process, labor management, and tower crane development.

Table 2-1. Differences between active and passive RFID tags

| Issues | Active RFID tags | Passive RFID tags |
|---|---|---|
| Power sources | Internal | Energy transferred from the reader |
| Power availability | Continuous | When it is in the field of the reader |
| Communication range | Up to 300 feet | Up to 40 feet |
| Data storage | Large | Small |
| Signal strength from tag to reader | High | Low |
| Signal strength from reader to tag | Low | High |
| Weight | 120-130 g | 6-54 g |
| Capabilities | Read/Write | Read only |
| Operational life | 5-10 years | Unlimited |
| Memory | 2 MB | Up to 16 kb |
| Cost ($) | 15-50 | 0.10-4 |

Adapted from http://www.inlogic.com/rfid/passive_vs_active.aspx

For example, active RFID system tags, which are built with a wide range of scanning capacity and internal battery, has been mostly used for material control management on construction job sites (Goodrum et al. 2005). The active RFID tag is, generally, capable of covering more than 1,000 feet of reading range (Lee et al. 2007).

Since active RFID systems have automatic data reading and recording capacity, material control systems using RFID DAT are more advantageous to productivity

enhancement, rather than the use of integration of barcode with PDA for material management in construction job sites (Navon and Berkovich 2005).

Table 2-2. Tag frequencies used by different countries

| Frequencies | Tags application areas | Costs ($) |
|---|---|---|
| 125-134 KHz | USA, Canada, Japan, Europe | 3 -10 |
| 13.56 MHz | USA, Canada, Japan, Europe | 0.5-5.00 |
| 433.05-434.79 MHz | In most of USA and Europe and under consideration in Japan | - |
| 865-868 MHz | Europe | - |
| 866-869 and 923-969 MHz | South Korea | 0.75 and up |
| 902-928 MHz | USA | 0.75 and up |
| 952-954 MHz | Japan (for passive tag after 2005) | 0.75 and up |
| 2400-2500 and 5.725-5.875 GHz | USA, Canada, Japan, Europe | - |

Adapted from Qiu (2007)

Another RFID DAT application was developed for safety management in the construction industry through the evaluation of past accident history. Chae and Yoshida (2009) developed the prototype to estimate the working area for the prevention of collision accidents. In this prototype, based on the record of past accidents, a defined function is applied to the RFID reader system and active RFID tags work as a alarm system if the estimation of working area is out of defined function (Chae and Yoshida 2009). This type of RFID DATs, referred to Automated Project Performance Control (APPC), requires the evaluation of past information to establish desired performance. On job sites, actual performance data are collected by RFID system, and the data are compared to the desired performance. When deviation is detected, the construction management should be analyzed (Navon 2007). Figure 2-3 illustrates a repetitive and cyclic process of Automated Project Performance Control system by RFID DATs.

Historical databases are used in comparing and analyzing the actual collected performance.

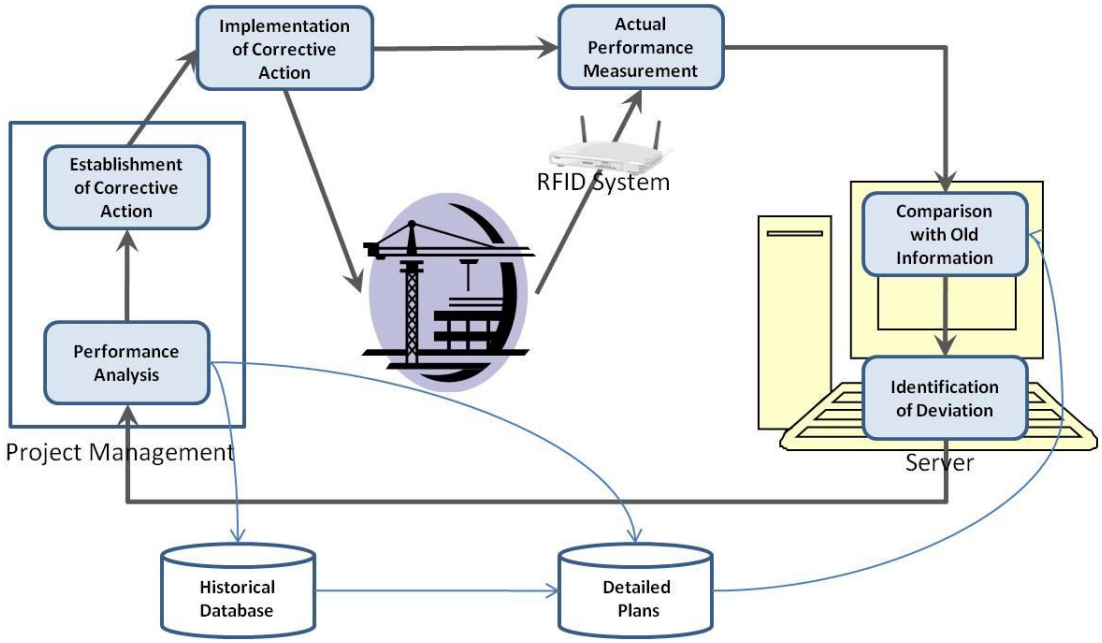


Figure 2-3. Automated Project Performance Control (APPC) by active RFID tag

Because of the reading and recording capability of active RFID tags, the RFID system can be applied to labor management process. All workers on job site are given a labor ID card with built-in active RFID tag and RFID readers around construction site track and record labor movement. Accurate data for workers' spent time and location are automatically acquired (El-Omari and Moselhi 2009).

As reviewed above, there is no doubt that RFID DATs are beneficial for effective construction data management. Although RFID DATs are widely accepted in many construction fields and their use has been shown to increase the effectiveness of data management for construction productivity, the use of individual RFID systems has its own limitations similar to other individual automated DATs (Jaselskis and El-Misalami 2003).

Installation costs, lack of standardization, and relatively limited reading range are considered as the main limitations of individual RFID use. Especially, in order to overcome the limited reading range of current RFID tags, integration of RFID with other location DATs has been proposed by many studies (Lee et al. 2007 and Chin et al. 2008).

The currently most used integration DAT is the RFID integrated with a GPS system enabling it to acquire more accurate location data for material management. Essentially, with the integration of RFID and GPS DAT in the material management process, construction materials tagged with RFID tags can be automatically identified and the exact location, even the distance from jobsite, can be simultaneously tracked (Song et al. 2006). This ability presents the potential for effective material management, and it can lead to productivity enhancement.

This integration of RFID with GPS also can be applied to the construction vehicle tracking process in order to facilitate arranging for the arrival of materials just in time and right quantity of materials to be delivered to construction jobsites (Lu et al. 2006). Another prototype of RFID with GPS DAT application is the intelligent tower crane operation framework as proposed by Han et al. (2004). Throughout their proposed tower crane framework, accurate information about materials' location is directly transferred to the crane operator and workers on the job site, reducing idle time for material delivery. The study identified that the tower crane operation equipped with RFID and GPS increased construction productivity by 20%. (Han et al. 2004).

In addition to the integration of RFID with GPS, other automated DATs are capable of integration with RFID systems and these provide more efficient data

collection process. For example, integrations of RFID with wireless DATs have the potential to be implemented in various construction activities. The integration of DATs based on the wireless internet environment enables construction manager to control and monitor construction operation by real-time. A prototype for wireless automated DATs' integration is proposed by Lee et al. (2006), using RFID+USN (Ubiquitous Sensor Network) technology. With this proposed framework, workers' performance data from construction site are easily collected by RFID+USN system, and construction managers can identify workers' location. More advanced integration of wireless technology with RFID systems stimulate to development of real-time safety monitoring system (Navon and Kolton 2007).

Another integration of RFID with other DAT may be the RFID+4D CAD model. Since 4D CAD is providing a schedule managing function in addition to 3D CAD model, the integration of RFID with 4D CAD is ideal for material management and schedule control. Chin et al. (2008) developed the RFID+4D CAD integrated model for structural steel work on high-rise buildings to identify productivity improvement. The developed model was applied to an actual steel work job site to identify productivity improvement. It was found that the RFID+4D CAD DATs offers more efficiency in process time in structural steel work (Chin et al. 2008).

As reviewed above, the integration of RFID with other DATs provides more efficiency for construction management, especially for material management, rather than the use of individual RFID systems.

**GPS (Global Positioning System)**

GPS technology is regarded as one of the most popular DATs in the construction industry. Automated GPS DAT is particularly useful for monitoring and controlling earthmoving operations in road construction.

Navon and Shpatnitsky (2005) pointed out that manual data collection methods in road construction involve lengthy and labor-intensive elements. They demonstrated how automated GPS technology can improve monitoring and controlling data collection, making timely and high data integration in road construction site. The project algorithm model was developed to convert collected data to productivity, progress, and materials consumption. They concluded that automated data collection systems with GPS yielded more accurate outputs than manual system. Using a GPS system in road construction increases production by 15-30%, increases profitability, dramatically reduces staking costs, and improves quality control (Navon and Shpatnitsky 2005).

In addition to the use of GPS systems in road construction, they can be used in geographical data collection systems. Lee and Han (2003) compared the performances and productivities between traditional system and GPS employed geographical data collecting system. A survey was conducted in this study, and they concluded that significant productivity enhancements were detected through all site work activities when a GPS system was used on the jobsite. Furthermore, the study indicated that the site work equipments' built-in GPS technology performed more accurately in cut and fill operations, and data recording process was more efficient than traditional recording systems (Lee and Han 2003).

The potential benefits of GPS DATs for material handling were described in a study by Caldas et al. (2006). This study was focused on the pipe locating process in

an industrial construction project. In order to verify the feasibility of material data acquisition, field trials were conducted. Caldas et al. (2006) concluded that the GPS deployment in industrial projects significantly saved time on data collection, and caused improvement of performance.

Typical GPS DAT consists of three subsystems, which are ground subsystems, positioning subsystems, and onboard subsystems (Lee and Han 2003). Figure 2-3 shows a typical GPS DAT system. A ground subsystem, in general, provides geometric data about the construction site with guidelines for construction equipment. Positioning subsystems transfer the required position data to the system and an onboard subsystem displays current position and required equipment functions.

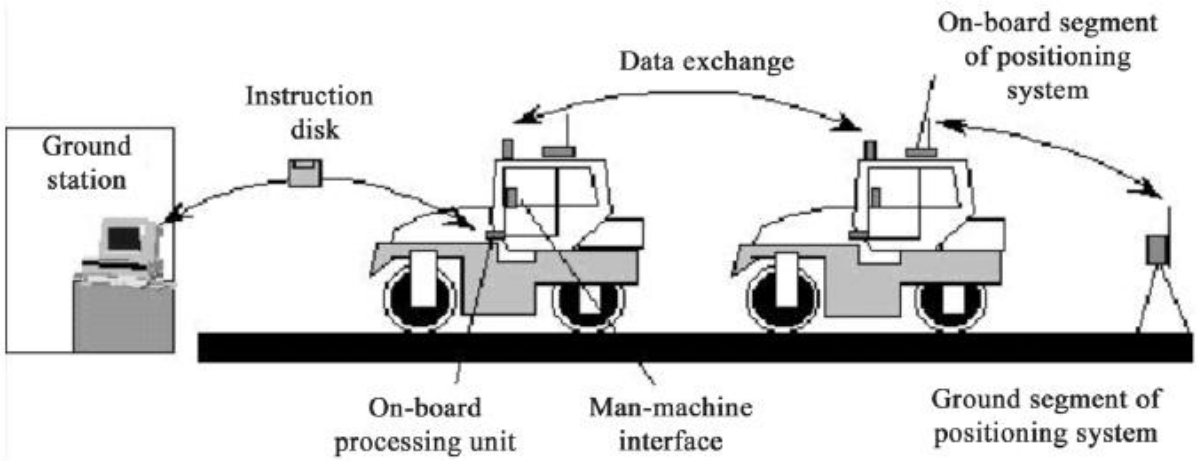


Figure 2-4. GPS data acquiring techonology (DAT) system (Hass 2000)

In order to maximize the efficiency of GPS utilization in construction projects, the adequate management of data collected by GPS is significant for successful construction management. In general, automated DATs including GPS generate enormous data volume (Seo et al. 2010). Therefore, data reduction processes for manageable data volume are required to increase efficiency of data management.

Hildreth et al. (2005) proposed a procedure for data reduction to facilitate automated data management. In order to improve the data management performance with data reduction process, they conducted field test using GPS. The collected data were analyzed with various statistical functions to identify critical data. Performing several field tests with statistical analysis, the number of data records was reduced by more than 95% (Hildreth et al. 2005).

The current GPS system, essentially, is ideal for positioning measurement. However, the suitability of GPS system is limited to road construction or site survey. Furthermore, the installation cost is relatively higher than other automated DATs' installation cost. These drawbacks can be alleviated by the integrating GPS with other DATs as previously described. Particularly, GPS systems are capable of being utilized with RFID systems for application to material management process thus enhancing accurate positioning measurement.

**PDA (Personal Digital Assistant)**

Since the mobile computing system was first introduced to public during the early 1990s, many efforts have been made to utilize PDA technologies for automated construction data management processes. The main advantage of PDA DATs is that the PDA enables construction workers to communicate each other. Also, the data generated from the job site can be stored in a small size storage device, and then transferred to the main office or to the supervisor without any documentation processes. Due to the ease of data management with PDAs, PDA data recording systems are rapidly being developed for the purpose of automated data management in the construction industry.

Recently, the advent of high-speed wireless network systems has advanced the development of PDA technology. In the wireless network environment, data collected by PDA can be transferred to the main server in the office. Frequently, automatic synchronizing software and web-integrated server system for PDA are used for easiness of data transmittance (Kim et al. 2007). The process of data management by PDA is illustrated in Figure 2-5.


Figure 2-5. Data processing by PDA in construction job site (Kim et al. 2007)

Although PDA systems have lots of benefits, there are several issues to be solved for further PDA utilization in construction data management. Cox et al. (2002) highlighted three problems related to usability and personal usage of PDA. One issue to consider was the cost. The cost for purchase and maintenance of PDA for site workers is not competitive in comparison with a manual system. Other problem of PDA on construction sites is a shortage of workers with technical skill to operate the PDA. The last issue to consider is that there are limited web based storage services to handle the collected data (Cox et al. 2002). However, most of construction professionals expect that these problems would be solved when PDA system is popularized in construction industry. As a result, supplemental web monitoring services will be developed to manage data generated from PDAs (Seo et al. 2010).

The PDA system also can be applied to labor management. Oh et al. (2004) proposed the labor management system using PDA for estimating accurate labor costs. They stressed that conventional workers' record systems were not accurate and caused overtime to be recorded. In order to improve labor management on the construction job site, they utilized PDAs to track workers to investigate management performances. With utilization of PDAs by workers, total labor costs were easily estimated, and each worker's time log was automatically stored to wireless accessible storage server devices. Furthermore, the automated labor data collection system by PDA enabled operators to manage the construction schedule (Oh et al. 2004).

**USN (Ubiquitous Sensor Network) and Other DATs**

With the recent rapid development and advancement of wireless technology, advanced wireless techniques are being combined with RFID for effective construction data management performance. As discussed previously, integrated RFID systems with wireless technology have alleviated the limitation of individual RFID use. Since USN is, recently, considered as one of the most advanced wireless techniques for construction data management, the integration of RFID with USN is primary concerned with increasing project data processing performance on large construction industry. USN is defined as wireless data transmission technology using wireless data communication systems with detecting sensors such as RFID (Lee et al. 2009). Zig-bee, CDMA, Wi-Fi, and Bluetooth are considered as main USN techniques. Table 2-3 summarizes the characteristics of each USN technique.

Lee et al. (2009) noted that USN technology has the capability to apply to automatic data management as a new intelligent system. For example, the

development of the integration of RFID+USN DAT is mainly focused on the capability of automatic capturing and management of construction data without any input by humans.

Table 2-3. The characteristics of USN techniques

| USN Technique | Characteristic | Advantages | Disadvantages |
|---|---|---|---|
| Zig bee | - IEEE 802.15.4 standard<br>- Combined with sensor<br>- Ideal for large area sensor network | - Low cost<br>- Low power operation<br>- Easy to use | - Short range of data transmission<br>- Sensitive to other signals |
| CDMA (Code Division Multiple Access) | - Enable to multiplex<br>- Special coding scheme to each transmitter | - Accurate location measurement<br>- Long range of data transmission<br>- Error free recording | - High cost of implementation<br>- Required for network infrastructure |
| Wi-Fi | - IEEE 802.11 standard<br>- High speed internet network | - Wide range of wireless network<br>- Stable network environment | - Not able to use during moving |
| Bluetooth | - Open wireless technology standard<br>- 1:1 or 1:n data transmission | - Low cost | - Limited network extension<br>- High power operation<br>- Short range of data transmission |
| UWB (Ultra Wide Band) | - Wide range of frequency level<br>- Low power operated | - High bandwidth communication<br>- Accurate locating and tracking | - Short range of data transmission<br>- Sensitive to other signals |

An example of a new intelligent construction data management system using RFID+USN was proposed by Cho et al. (2010). They pointed out that automatic

construction material locating measurement is significant in reducing waiting time for material delivery in high rise building construction. The intelligent construction lift car toolkit as shown in Figure 2-6 was implemented with USN technology. The gathered information from RFID sensors also can be used for monitoring overall construction status (Cho et al. 2010).

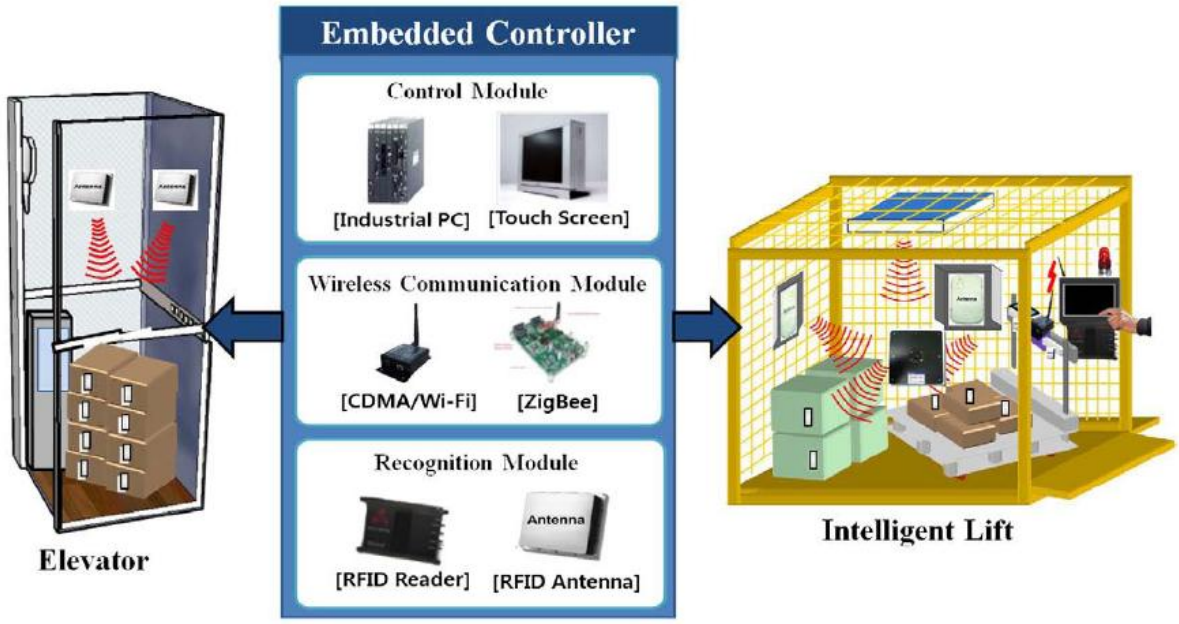


Figure 2-6. Illustration of the intelligent lift toolkit concept for elevator and intelligent lift (Adapted from Cho et al. 2010)

The RFID+USN DAT approach is most accepted in the material and labor management area because it allows accurate location measurement on construction sites. Recent advancements of USN technology have led to the use of the Real Time Locating System (RTLS), which is an advancement of the data collecting system (Lee et al. 2010). Through the deployment of RTLS on construction sites, operators are able to collect accurate real-time construction data for material and safety management.

Both USN and RTLS technologies are required to adopt localization techniques in order to identify objects within wireless networks. Figure 2-7 illustrates the concept of

the wireless localization technique. The main localization principles and advantages of USN and RTLS are listed in Table 2-4.

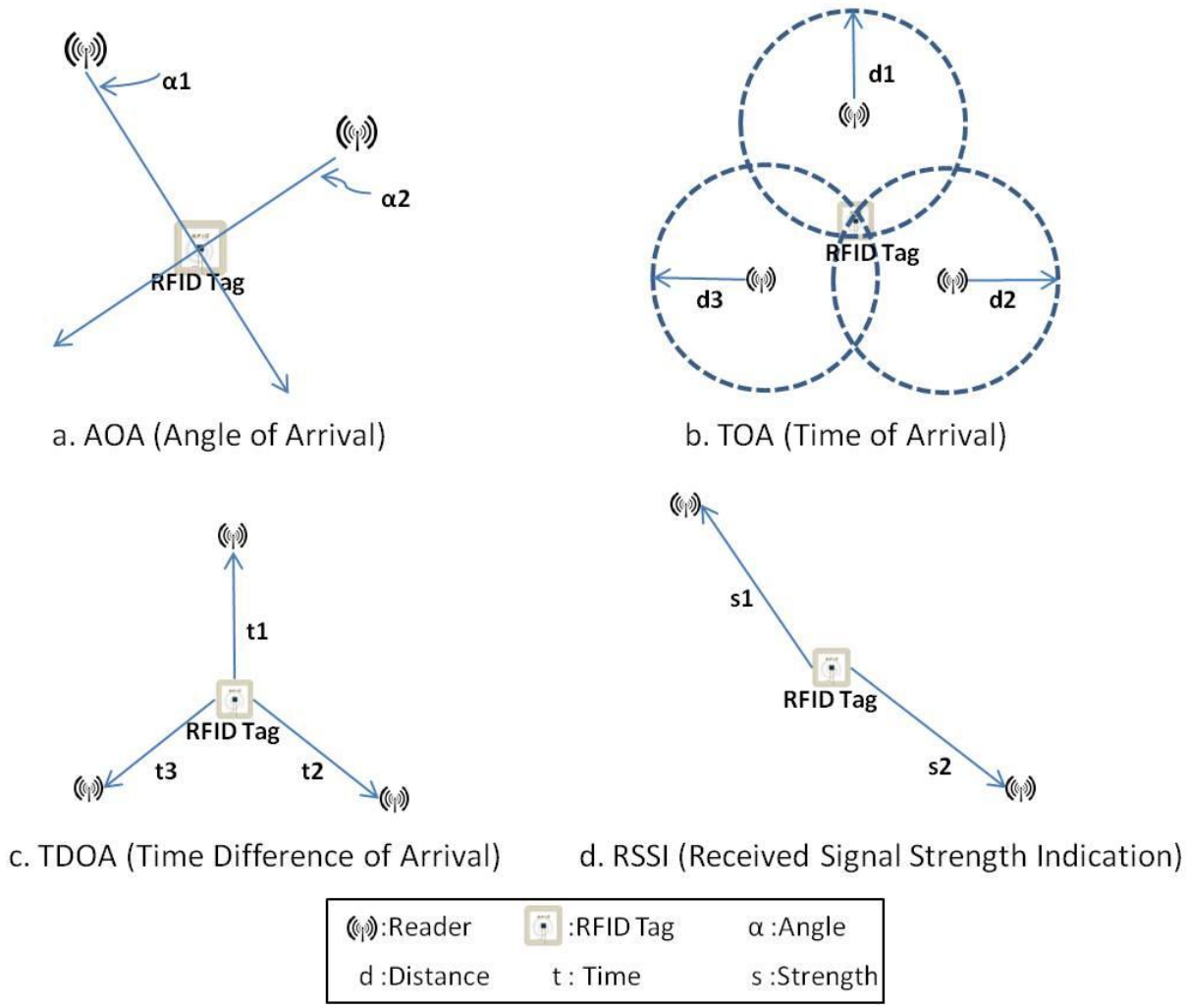


Figure 2-7. The concept of wireless localization techniques for USN and RTLS

Among these principles, the Angle of Arrival (AOA) system is the most sensitive to environmental conditions causing inaccurate data collection. The Received Signal Strength Indication system (RSSI) frequently gathers erroneous data from sensors, so it is not adequate for application to construction fields. The Time Difference of Arrival (TODA) principle requires the time synchronizing process even though it offers accurate data collection system. As compared with all these, the Time of Arrival (TOA) technique

provides the most precise data collection with a wide range of reading capabilities (Lee et al. 2010).

Table 2-4. Main localization techniques for USN and RTLS

| Localization Techniques | Process | Advantage |
|---|---|---|
| AOA (Angle of Arrival) | The directional antennas arrays are used to measure the direction of the transmitted signal. The location of the RFID tag can be determined at the intersection of the two angled directional lines. | Location can be measured by only two readers |
| TOA (Time of Arrival) | The signal traveling time between a RFID tag and a specific reader is measured for calculating the distance. Once the transmission radii are measured, the location of the RFID tag can be determined using geometrical triangulation methods (intersection of three distance circles as shown in Figure 2-7b). | Most accurate positioning information can be measured |
| TDOA (Time Difference of Arrival) | Similar to TOA process. The time difference of arrival of the signal transmitted from readers is measured to determine the RFID tag location. (Figure 2-7c) | Fast time synchronization is available |
| RSSI (Received Signal Strength Indication) | The distance between a reader and a RFID tag can be estimated by calculating the attenuation of the emitted signal strength being received. | Possible for measuring 3D locating information with adequate software |

**Integration of DATs**

As presented above, individual automated DATs such as RFID, GPS, and PDA have their own limitations and disadvantages even though each DAT promotes construction performance and data management. Furthermore, individual DATs are just beneficial for a specific construction area. For example, RFID and PDA technologies were mainly used in material tracking and labor management, respectively. In earth work sites, the GPS system is dominant for construction data management (Giretti et al. 2009). For the purpose of overcoming these limitations to automated DATs' independent use in certain areas, integrated DATs are crucial for effective construction data management process.

Especially, the RFID system has the capability for combining with other DATs to enhance construction data handling by automatic transmission (Choi 2004). For instance, the representative RFID integration techniques are the RFID system combined with GPS, PDA, 4D modeling, and USN. Other examples of DATs' integration were proposed in the study by Omari and Moselhi (2009). They proposed virtual DATs integration model is RFID combined with a 3D scanning system. This integration of DAT is capable of capturing text and 3D graphical image data to report construction progress.

Based on the literature reviews, this study has determined that the RFID technologies and integration of RFID with other DATs are widely expected to improve data management on construction projects. Moreover, it was also determined that barcode systems are mostly replaced with the RFID technologies due to the disadvantages of barcode systems. PDA technology is also widely applied to

construction jobsites to collect data. Another significant identification from the literature review is that advanced sensor network data collecting systems, such as the RFID system with USN or RTLS, have a great potential for advanced DATs' development. In closing, the approaches to new integration of DATs will lead future researches to concentrate on the improvement of construction data management.

## Overview of Bayesian Belief Networks

As reviewed above, several integrations of DATs are required to be developed and to be accepted by the construction industry in order for effective construction data management to be possible. One of the primary benefits of the integration of DATs is that it has capability to overcome the limitation of independent or single DAT use on construction site. For example, RFID system use enables automatic recording of construction data, and it causes improvement in construction productivity and reductions in labor cost and time. However, there is no valid procedure to transfer and manage the data from an RFID system (Cho et al. 2010). In order to eliminate the disadvantage of single RFID use, other DATs, such as GPS, PDA, USN and 4D CAD are required to be integrated with the RFID system.

Although it is evident that integration of DATs improves construction productivity and effective data management, some contractors have not deployed automated DATs on their construction project because of the installation cost of DATs and uncertainties about DATs' performance (Seo et al. 2010).

The main purpose of this study is to quantify the potential benefits of the integration of automated DATs, and to establish the development of methods for each DAT's evaluation. In this study, the Bayesian belief network, also referred to as

Bayesian network or belief network is employed to quantify the potential benefits of automated DATs' integration.

**Characteristics of Bayesian Belief Networks**

The Bayesian belief network (BBN) is a form of artificial intelligence that incorporates uncertainty through probability theory and conditional dependence, and it was first developed at Stanford University in the 1970s (McCabe et al. 1998). In other words, a Bayesian belief network describes probabilistic relationships among a set of variables by determining cause and effect relationship through graphical models (Luu et al. 2009).

Since a Bayesian belief network constructs a cause and effect diagram, it is considered as powerful tool for knowledge representation and reasoning under uncertainty conditions (Cheng et al. 2002). The main advantages of Bayesian belief network are summarized as follows;

- Bayesian belief networks (BBNs) provide great flexibility in their capacity for accepting input and providing output.
- BBNs have the ability to allow the value of a variable to be entered as a known input or to evaluate the likelihood of a variable as an output of the system
- BBNs can readily calculate the probability of events before and after the introduction of evidence and update its diagnosis or prediction
- Belief networks may be developed using expert opinion instead of requiring historical data
- Belief networks also allows variables to be added or removed without significantly affecting the remainder of the network because modifications to the network may be isolated

Fundamentally, a Bayesian belief network consists of nodes, representing variables of the domain, and arcs, which represent the relationships between the nodes

(McCabe et al. 1998). Figure 2-8 presents a simple belief network related to construction activity. Child nodes are conditionally dependent upon their parent nodes.

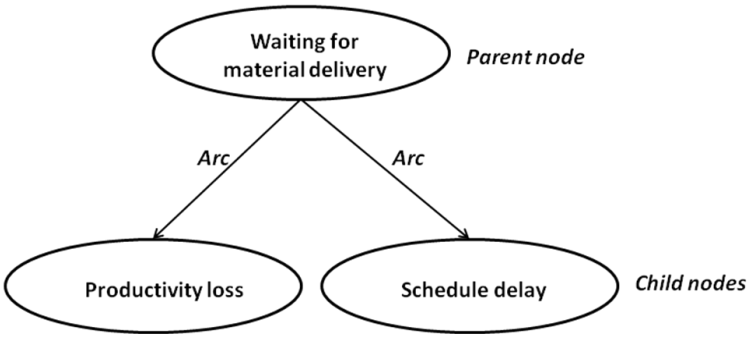


Figure 2-8. A simple belief network of construction activity

BBNs are based on Bayes' theorem, which follows from the basic conditional probability relationship. Bayes' rule can be simply expressed as follows;

$$P(B|A) = \frac{P(A|B) \times P(B)}{P(A)}$$

where P(A) is the probability of A, and P(A|B) is the probability of A given B has occurred.

Specifically, a well designed BBN development requires following steps (Poole et al. 1998):

- Define the relevant variables.
- Define the relationship between the variables.
- Define the states of the variables. This step requires defining the detail level of the system.
- Define the conditional probabilities of the relationships.

More specifically, BBN development consists of qualitative and quantitative parts (van der Gagg 1996). The qualitative part of BBN, which is called structural learning, is

the graphical representation of independence (Lee et al. 2009). The main purpose of this part is to identify significant causal factors applicable to the BBN analysis.

The quantitative part of the BBN, the so-called parameter learning, is the process of finding dependence relations as joint conditional probability distributions among variables using cause and effect relationships from the qualitative part to develop the BBN model (Lee et al. 2009).

In the construction industry, the BBN can be a suitable methodology for project risk management (Lee et al. 2009) and construction performance diagnostics (McCabe et al. 1998).

**Use of Bayesian Belief Networks in the Construction Industry**

Due to the easiness of cause and effect calculation and identification in the BBN model, BBNs can be used as a diagnostic tool in order to obtain the probabilities of variable factors in construction performance.

McCabe et al. (1998) described the automated approach for the improvement of construction operations integrating BBNs and computer simulation. The computer simulation represents the construction operation whereas the BBNs provide expert analysis of the performance of the operation (McCabe et al. 1998). Figure 2-9 shows the prototype of the automated process. In this application, the BBN provided diagnostic analysis of the simulated construction performance with the generation of recommendations for remedial actions that can improve the performance.

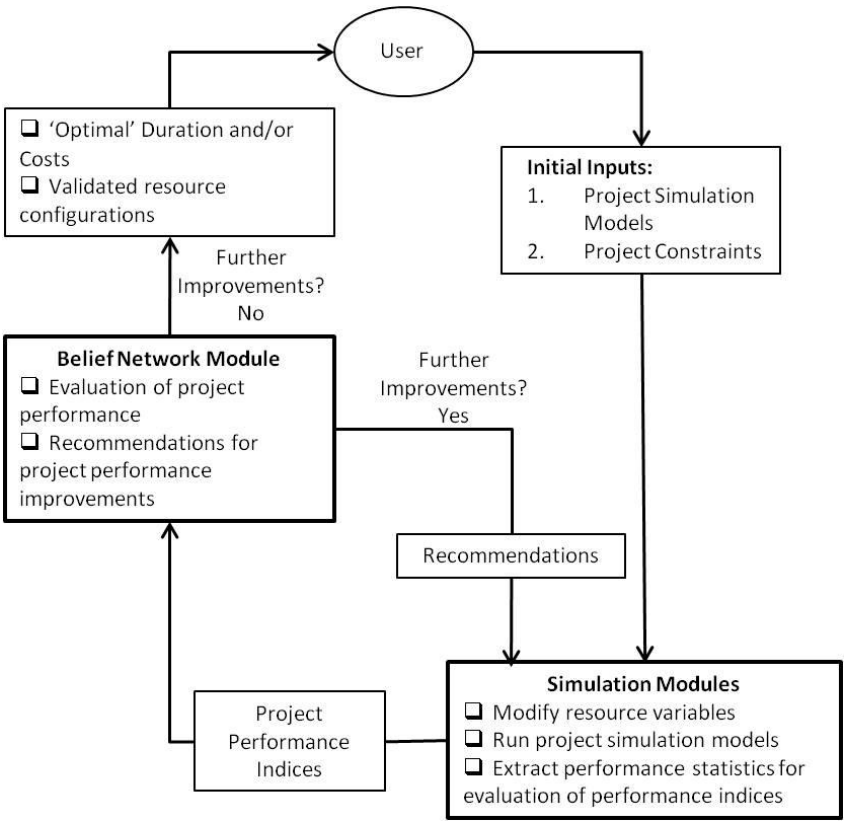


Figure 2-9. Automated process for integration of BBNs and computer simulations (Adapted from McCabe et al. 1998)

Luu et al. (2009) applied the BBNs to quantify the probability of construction projects delays in Vietnam. In order to develop the BBNs, qualitative and quantitative analysis were performed. For the requirement of qualitative analysis, factors were identified through a survey questionnaire. For the quantitative part of the BBNs, the cause and effect relationships among the factors were obtained through the use of expert interviews (Luu et al. 2009). Then, they developed the BBN using the Microsoft Belief Networks software, MSBNx (http://research.microsoft.com/en-us/um/redmond/groups/adapt/msbnx/). The conceptual BBN model is shown in Figure 2-10. Through the BBN analysis, they concluded that construction delays are extremely

sensitive to actors related to ‘shortage of materials’, ‘defective construction work’, and ‘slow site handover’ (Luu et al. 2009).

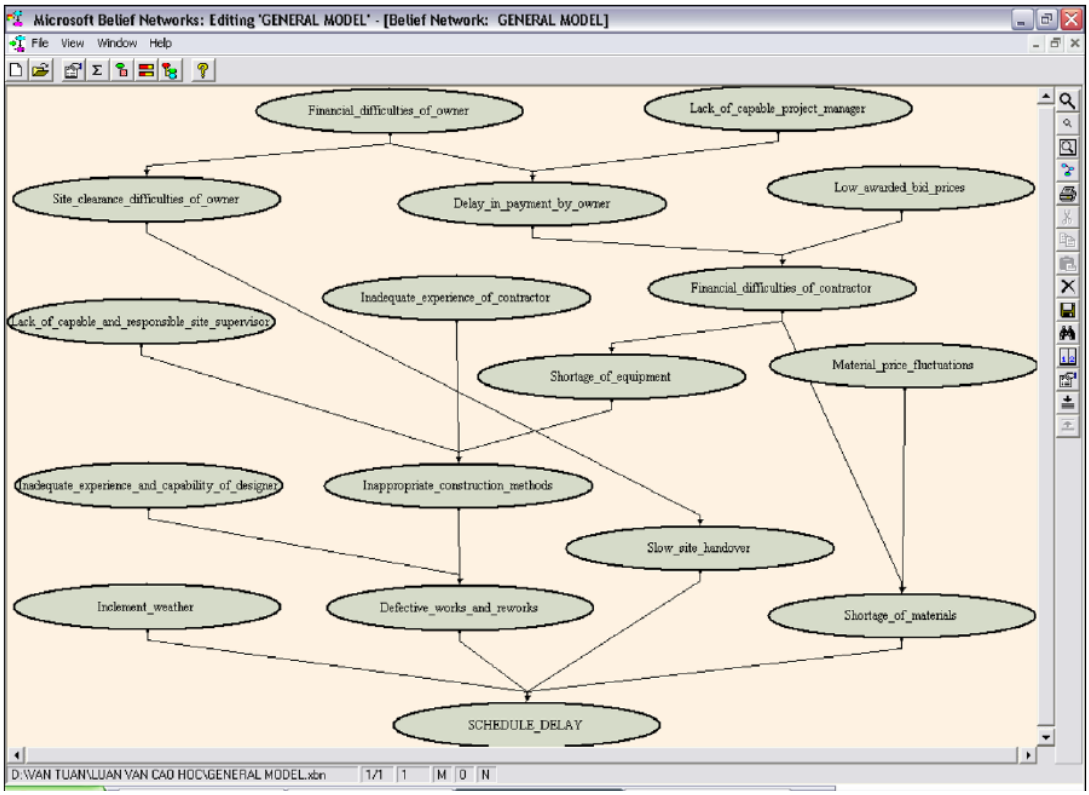


Figure 2-10. The conceptual BBN-based model for predicting the probability of construction delay (Luu et al. 2009)

# CHAPTER 3
# METHODOLOGY

## Overview

The main objective of this study is to look at current automated DATs development and to quantify the potential benefits of the integration of automated DATs for effective data management in the construction industry. In order to quantify the benefits of DATs, Bayesian belief network analysis was used in this study. In order to identify the benefits of DATs, the following steps were followed:

- An evaluation of previous studies and literature reviews about automated DATs was conducted to collect information about the development history of DATs and to identify current trends of DATs use on construction projects.
- The survey questionnaires were developed to obtain the data about current DAT uses and to identify the DAT use preferences in construction companies.
- The dynamic survey form was created by Adobe LiveCycle Designer ES2 enabling web-based tracking with real time update, and the form was sent to upper level management personnel in each construction company
- Construction companies in South Korea have a great tendency of using state-of-the art technologies' on their construction projects (Seo et al. 2010). In order to obtain most current data about DATs, the respondents were randomly selected based on the list of 1000 Top Construction Companies of 2009 provided by the Construction Association of Korea.
- The data collected from the survey were analyzed in detail.
- In order to quantify the potential of automated DATs in the construction industry, the Bayesian belief network (BBN) model was developed using the data from the survey and literature reviews.
- In the BBN model, changing the conditional probabilities of the negative factors was performed based on the survey results. This is also called reduction of negative factors.
- Through the BBN model, the effects of the DATs' integration with construction data management were evaluated by measuring the probability of the successful performance of a given task.

**Identification of the Negative Factors Affecting Construction Data Management**

In Chapter 2 of this study, published literatures were reviewed to identify negative factors that affect construction data management practices. Of the observed risk factors, the external factors which are not related to data management were not considered for this study. Instead, the internal risk factors related to material, labor, safe, schedule, and quality management were evaluated.

The survey was also conducted to identify the negative factors that prevent effective data management in the current construction industry. Since the identified factors from the survey would be used as variables in the BBN analysis and the correlations of all factors are significant to develop the relationships of each variable in the BBN model, each question of the survey was connected and correlated with other questions which might be complicated and might cause respondents' inconsistent answers. Therefore, in order to obtain consistent and accurate survey results from the respondents, an advanced survey method is required for the development of BBN model.

Specifically, for obtaining accurate survey answers and for respondents' convenience, a dynamic survey form was created using Adobe LiveCycle Designer version of ES2.

With this dynamic survey form, respondents would be asked to answer to different questions according to their previous choices. For example, the negative factors in relation to construction data management were initially defined based on the literature reviews and expert advice. The predefined negative factors were provided in Question 5 where the respondents were asked to choose all negative factors that affected their construction performance and to rate the degree of the effects as either high effect,

medium effect or low effect. Question 6 asked the respondents to input the probability of occurrence of their selected factors based on the choices they made in Question 5, as shown in Figure 3-1. Based on the respondents' choice, the effect levels of the factors were calculated by multiplying the degree of the factors by the probability of occurrence. The averaged effect level of the factors would be used as the state level of each node in BBN model.

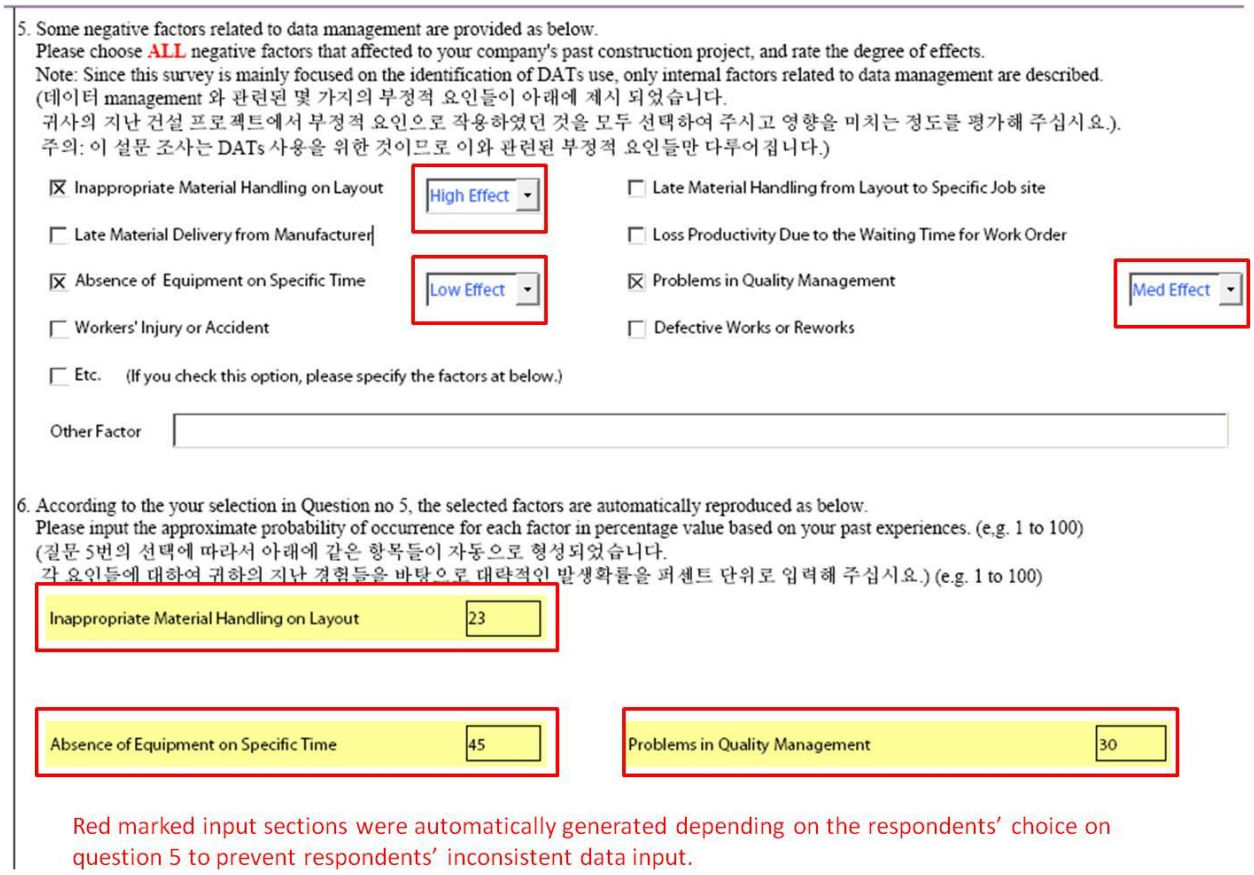


Figure 3-1. Dynamic survey form used for this study.

This dynamic process greatly reduced the rate of respondents' inconsistent answers. In this study, no inconsistent survey answers were identified. Moreover, respondents could easily submit the survey form with just one click, and the collected survey forms

were automatically stored and organized depending on distributor's choice. The full dynamic survey form is provided in Appendix A.

For this study, two hundred and twenty five respondents were randomly selected from the list of the 1000 Top Construction Companies of 2009 provided by the Construction Association of Korea. Seventy three responses were received, representing a response rate of 32%.

### Identification of the Current DATs Implemented in Construction Industry

In order to identify the current DATs implemented in construction companies, published literature was reviewed according to the type of DATs and a survey was conducted.

In the survey questionnaire, respondents were asked to answer whether DATs were implemented on their projects or not. If respondents answered that they were using DATs on their projects, the question asking the types of DATs that they implemented would be automatically generated in the dynamic survey form. Similarly, the question asking the reasons for their hesitation in DATs implementation would appear if the respondents answered that DATs were not being used on their projects.

### Determination of the Relationships between Negative Factors

As presented above, the relationships between factors are significant to develop BBN model. Throughout the survey and literature reviews, the correlations of factors were determined. The acquired relationships between factors would be represented as arc in the BBN analysis model.

In the survey questionnaire, respondents were asked to rate the degree of relationships between factors such as strong relationship, somewhat relationship, and

low relationship. According to the survey results, cause and effect relationships were identified and ranked by averaged degree of relationships.

In this study, only the controllable internal factors which are related to the data management were considered.

## Development of BBN Model

### Overview

Based on the results of survey and literature reviews, the Bayesian belief network (BBN) was developed to quantify the potential benefits of integration of DATs in construction industry. The qualitative and quantitative analysis phases are required to develop a BBN model (Lee et al. 2009). The BBN development process for this study is illustrated in Figure 3-2.

For the evaluation of the negative factors' effects level, eight of predefined negative factors based on literature reviews were provided to survey respondents. Those are directly related to construction data management practices. The calculated effect levels of factors were applied to the assigning the conditional probabilities to factors.

The relationships of all factors were evaluated by survey results. All dataset for identification of the relationships from survey were averaged and applied to a BBN model to describe correlation of all factors.

Two BBNs models were constructed for large and small sized construction companies to compare the integration of DATs effects. In this study, GeNIe Ver. 2.0 (http://genie.sis.pitt.edu/) was adopted for BBN analysis.

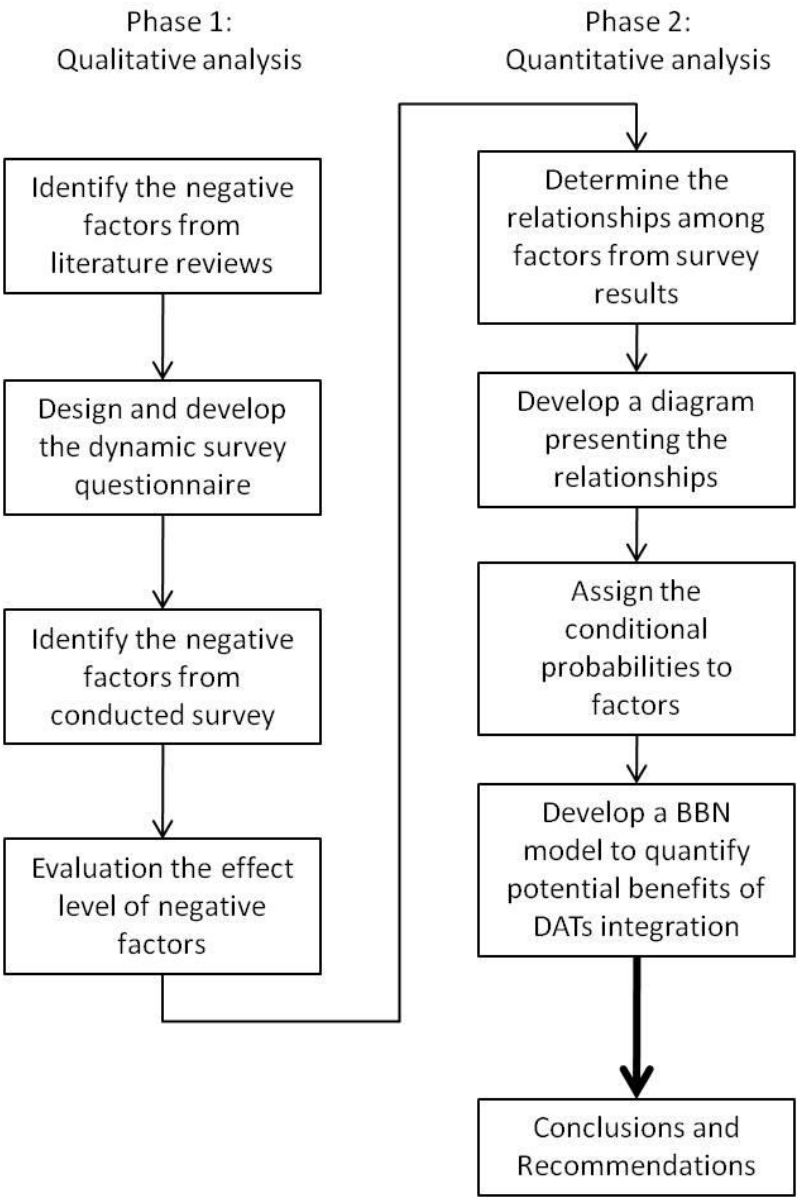


Figure 3-2. The development of a BBN model procedure for this study.

**Evaluation of the Negative Factors**

For the development of a BBNs model, the negative factors related to construction data management were defined based on literature reviews. The predefined negative factors are summarized in Table 3-1.

Table 3-1. List of predefined negative factors related to construction data management

| Predefined Negative Factors | Model Variables |
|---|---|
| Inappropriate material handling on layout | F1 |
| Late material handling from layout to specific job site | F2 |
| Late material delivery from manufacture | F3 |
| Loss productivity due to the waiting time for work order | F4 |
| Absence of equipments on specific time | F5 |
| Problems in quality management | F6 |
| Workers' injury or accident | F7 |
| Defective works or reworks | F8 |

These eight predefined negative factors were used as variables, referred to nodes, for BBN model as shown in Figure 3-3. This procedure is known as qualitative analysis for BBNs development.

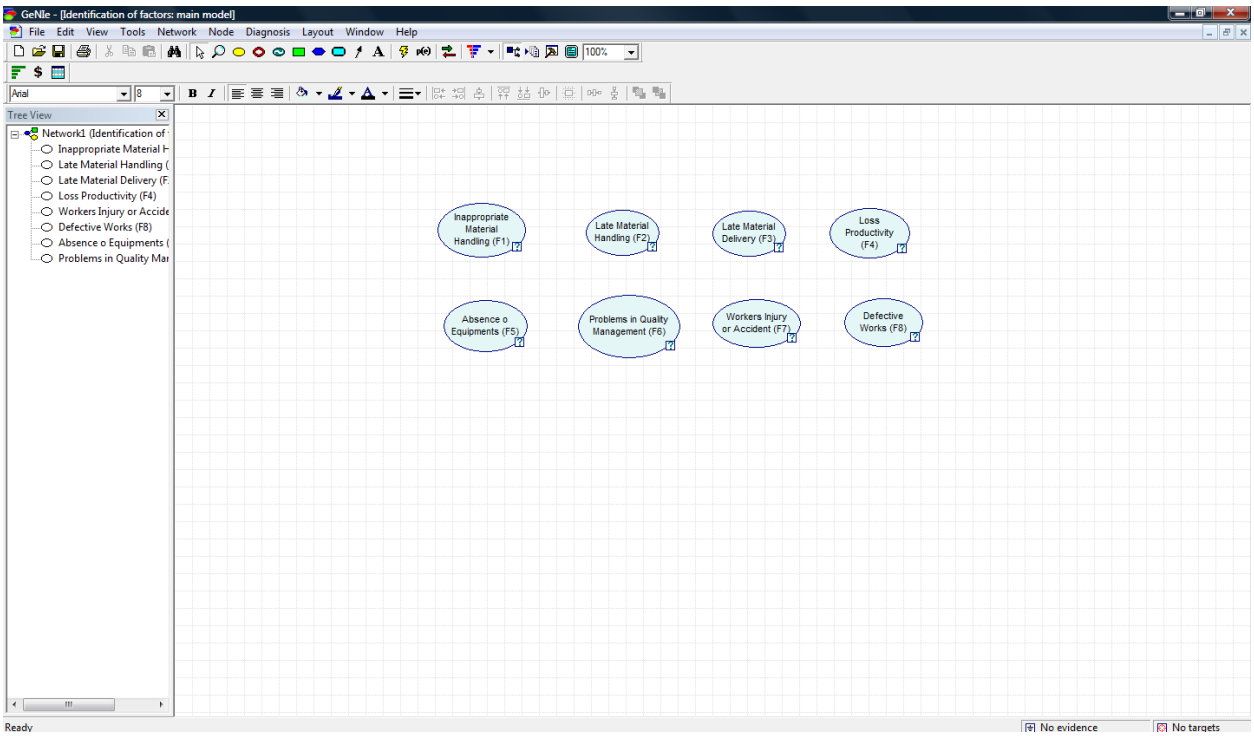


Figure 3-3. The development of predefined negative factors that affect to construction performance in GeNIe Ver.2.0

**Determination of the Relationships among the Factors**

Determination of the relationships among the factors identified in the qualitative analysis phase was performed through the survey. The determined relationships represent the cause and effect of the factors.

In this study, two different relationships were determined based on the size of the companies. The large size company is classified that the annual revenue for past year was over $100 million. On the other hand, the company that the annual revenue was below $100 million was classified as small company. Of the seventy three answered respondents, twenty nine companies were classified as large size company, and forty four responses were considered as small size company.

In addition, through the survey, respondents were asked to specify the relationships among the eight factors with request for rating the degree of relationship. In order to rank significant relationships among the factors, three degree of relationships phase were provided to survey questionnaire. Each phase of degree was assigned with constant number. That is ‘3 for strong relationship’, ‘2 for somewhat relationship’, and ‘1 for weak relationship’.

The survey answers were statistically analyzed to validate significant pairs of factors by the size of company. Of the many possible pairs of factors, top of 15 pairs of factors were determined to apply to BBN model.

Table 3-2 and Table 3-3 show the cause and effect relationships among the factors in large size company and small size company, respectively. The model variables encoding in Table 3-1 are used.

Table 3-2. Fifteen cause and effect relationships among the factors in large size company

| Rank | Relationships | Mean Constant Value |
|---|---|---|
| 1 | F3 - F4 | 2.48 |
| 2 | F2 - F3 | 2.21 |
| 3 | F1 - F2 | 2.19 |
| 4 | F2 - F4 | 2.05 |
| 5 | F1 - F6 | 1.98 |
| 6 | F4 - F7 | 1.98 |
| 7 | F4 - F5 | 1.84 |
| 8 | F2 - F6 | 1.51 |
| 9 | F6 - F8 | 1.33 |
| 10 | F4 - F8 | 1.18 |
| 11 | F3 - F5 | 1.01 |
| 12 | F5 - F6 | 0.99 |
| 13 | F4 - F6 | 0.86 |
| 14 | F1 - F8 | 0.85 |
| 15 | F3 - F6 | 0.65 |

Table 3-3. Fifteen cause and effect relationships among the factors in small size company

| Rank | Relationships | Mean Constant Value |
|---|---|---|
| 1 | F2 - F4 | 2.74 |
| 2 | F3 - F4 | 2.36 |
| 3 | F2 - F3 | 2.20 |
| 4 | F6 - F8 | 2.14 |
| 5 | F1 - F4 | 2.02 |
| 6 | F5 - F8 | 1.87 |
| 7 | F1 - F2 | 1.74 |
| 8 | F2 - F6 | 1.59 |
| 9 | F2 - F8 | 1.40 |
| 10 | F1 - F5 | 1.19 |
| 11 | F3 - F6 | 1.12 |
| 12 | F3 - F8 | 1.00 |
| 13 | F4 - F8 | 0.81 |
| 14 | F7 - F8 | 0.62 |
| 15 | F4 - F5 | 0.38 |

Based on the 15 determined cause and effect relationships among the factors, the identified factors in Figure 3-3 was modified as shown Figure 3-4 and 3-5 for large and small size company, respectively.

Two simple developed BBN models represent that construction performance is mainly affected by the problems in quality management (F6) and loss productivity (F4). In comparison with the relationships among the factors for large and small company, it is found that the factor of problems in quality management (F6) in large company is more affected by other factors than small company.

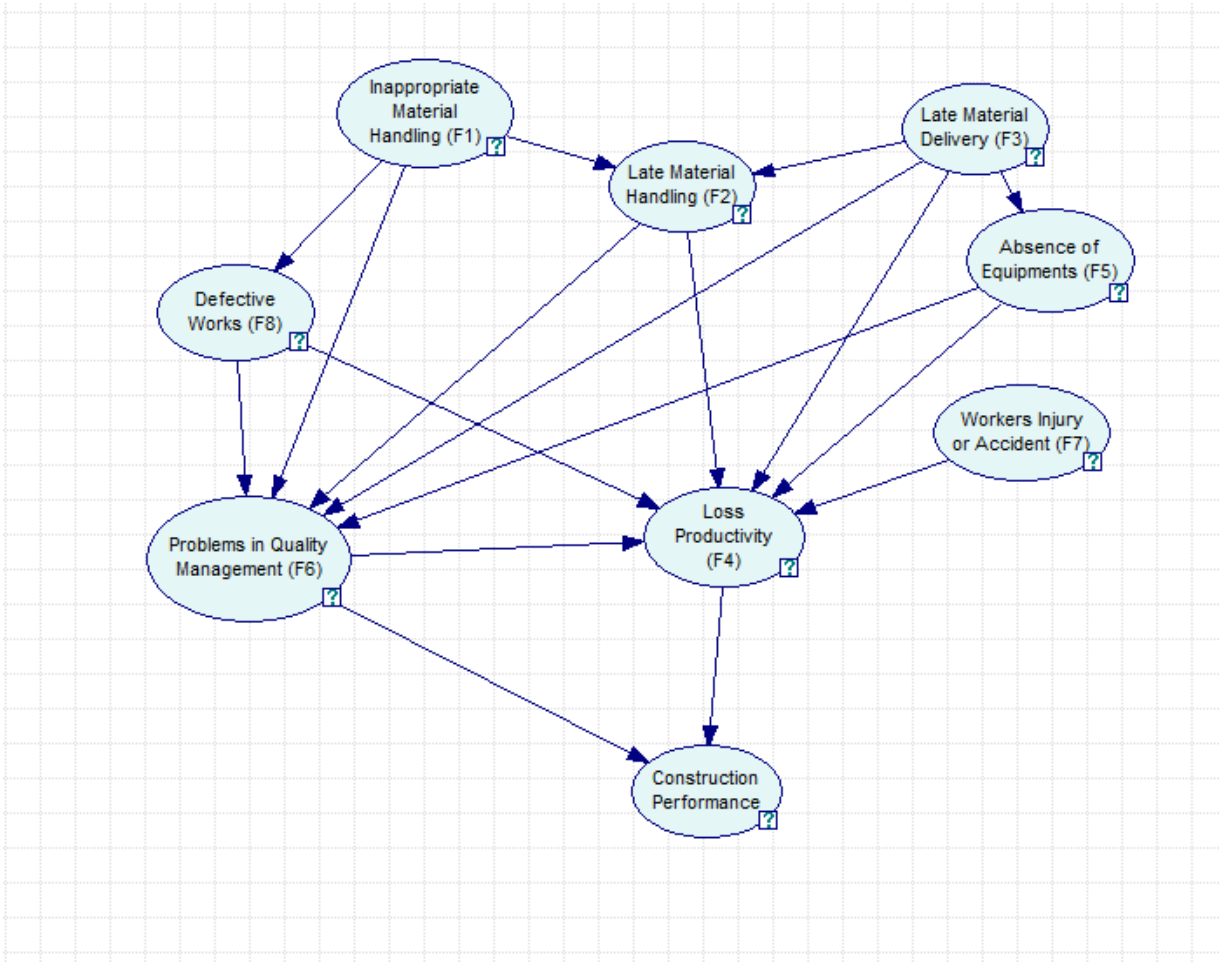


Figure 3-4. The development of relationships among factors for large size company

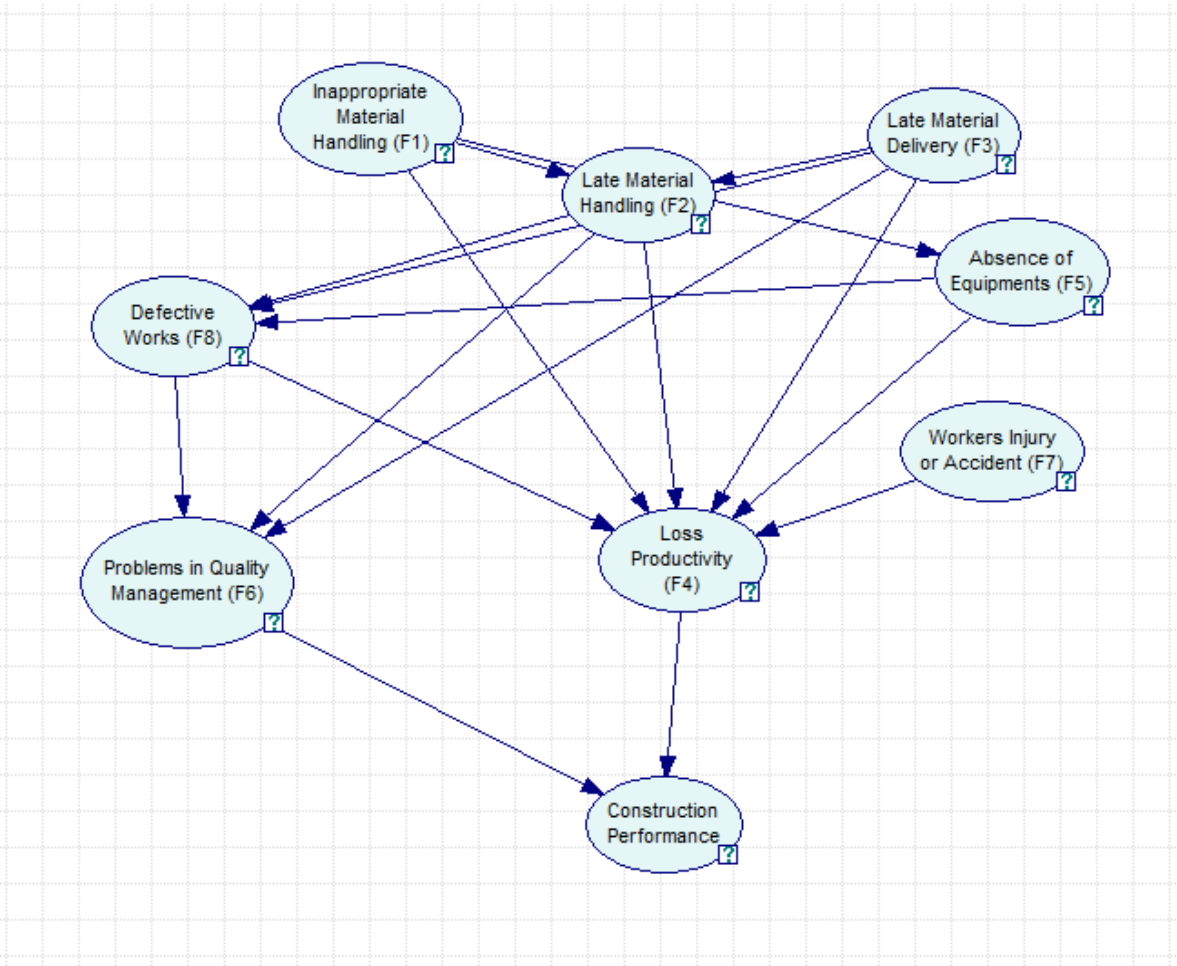


Figure 3-5. The development of relationships among factors for small size company

**Assigning the Conditional Probabilities to Factors**

The negative factors related to data management that affect to construction performance was identified, and the relationships for large and small companies were determined based on literature reviews and conducted survey. As a final step for BBNs development, the conditional probabilities need to be assigned to each factor. In order to assign probabilities to a BBN model, the survey answers of part 2 were used. In part 2 in the survey, respondents were asked to choose the degree of effect and to input the probabilities of occurrence for all factors that are selected by them. The degrees of

effect were divided into three phase with assigning constant numbers such as ‘3 for high effect (HE)’, ‘2 for medium effect (ME)’, and ‘1 for low effect (LE)’. Multiplying assigned constant numbers according to the degree phase to probabilities of occurrence represents the effect level.

With the evaluation of the survey answers, the effects level of negative factors for large and small companies were calculated and organized in Table 3-4 and Table 3-5, respectively. The serious negative factor affecting construction performance in large companies is loss productivity due to the waiting time for work order (F4). On the other hand, in small companies, workers injury and accident (F7) is regarded as serious negative factors.

Table 3-4. The averaged occurrence probabilities of negative factors that affect to construction performance in large companies (%)

| Model Variables | Factor | High Effect (HE) | Medium Effect (ME) | Low Effect (LE) |
|---|---|---|---|---|
| F1 | Inappropriate material handling on layout | 32.5 | 41.7 | 25.8 |
| F2 | Late material handling from layout to specific job site | 37.2 | 60.8 | 2.0 |
| F3 | Late material delivery from manufacture | 25.9 | 50.4 | 23.7 |
| F4 | Loss productivity due to the waiting time for work order | 39.2 | 44.5 | 16.3 |
| F5 | Absence of equipments on specific time | 12.4 | 22.9 | 64.7 |
| F6 | Problems in quality management | 37.2 | 36.4 | 26.4 |
| F7 | Workers’ injury or accident | 24.9 | 33.6 | 41.5 |
| F8 | Defective works or reworks | 28.6 | 39.5 | 31.9 |

Table 3-5. The averaged occurrence probabilities of negative factors that affect to construction performance in small companies (%)

| Model Variables | Factor | High Effect (HE) | Medium Effect (ME) | Low Effect (LE) |
|---|---|---|---|---|
| F1 | Inappropriate material handling on layout | 29.9 | 52.6 | 17.5 |
| F2 | Late material handling from layout to specific job site | 22.7 | 53.7 | 23.6 |
| F3 | Late material delivery from manufacture | 32.1 | 49.2 | 18.7 |
| F4 | Loss productivity due to the waiting time for work order | 19.5 | 62.7 | 17.8 |
| F5 | Absence of equipments on specific time | 22.4 | 36.1 | 41.5 |
| F6 | Problems in quality management | 22.4 | 57.6 | 20.0 |
| F7 | Workers' injury or accident | 33.9 | 39.2 | 26.9 |
| F8 | Defective works or reworks | 29.5 | 41.4 | 29.1 |

Figure 3-6 shows the initially developed BBN model which the factors' probability of occurrence for large companies (from Table 3-4) were applied to the model. In this BBN model, the probability value of each node is different with the value from Table 3-4. That is because the probability values in Table 3-4 are present the probability of each factor that affects to construction performance. But during the development of BBN model, each probability value from Table 3-4 was recalculated depending on the relationships among the factors based on conditional probability. And, in the construction performance nodes, each states was initially input by the probability of 33% to easily track the probability changing after parameter learning process. Parameter learning process in the GeNIe Ver.2.0 is used to calculate the conditional probability of each factor nodes.

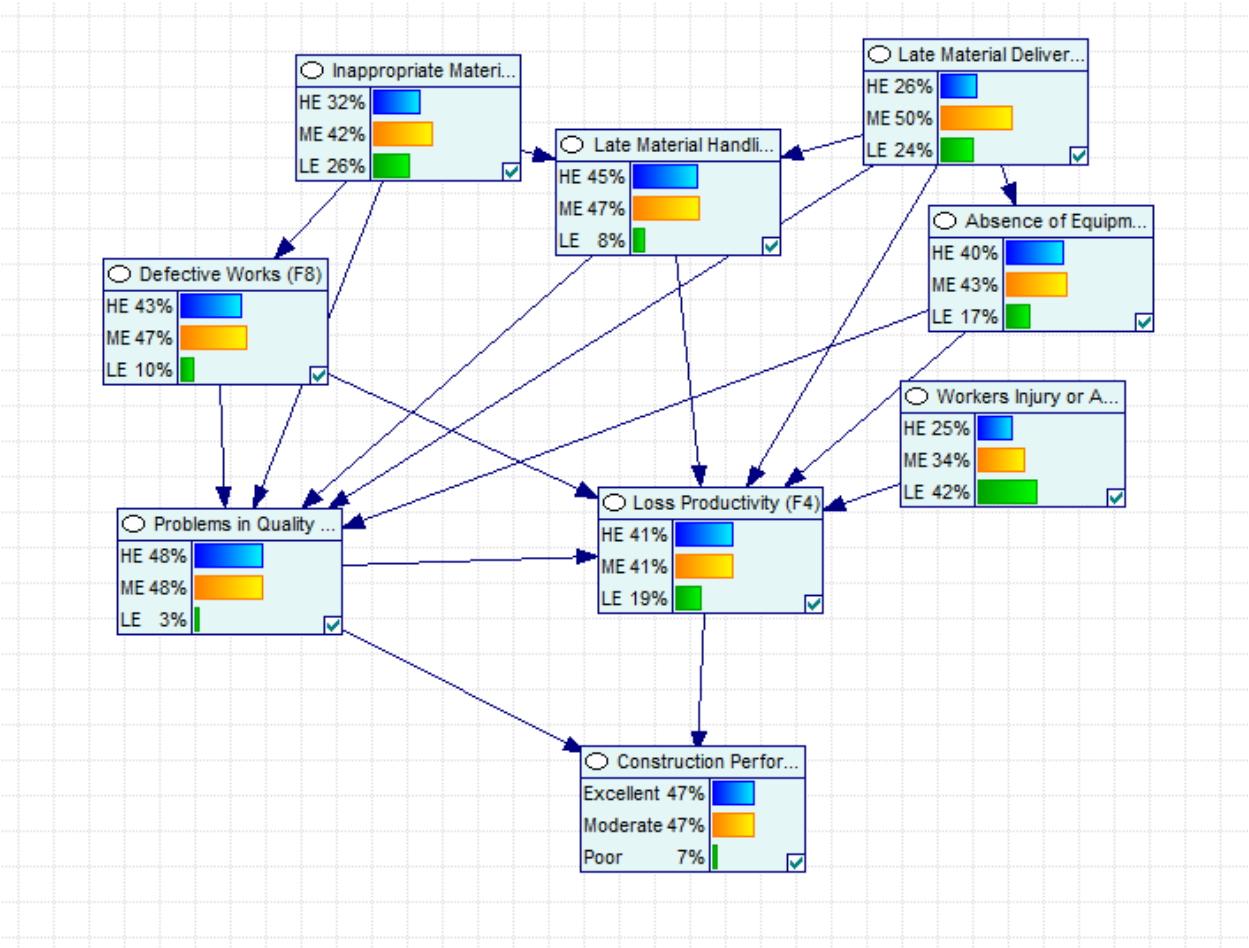


Figure 3-6. The initial BBN development with probability of occurrence of each factors for large companies

With the same method, the initial BBN model for small companies was developed as shown in Figure 3-7. Even though the parameter analysis process for conditional probability of each node was not conducted, it is found that the small companies have more chance of poor construction performance. It can be inferred that the probability of negative factors' occurrences between large and small companies are different. Moreover, the different relationships among factors were identified through the initial BBN models for large and small companies.

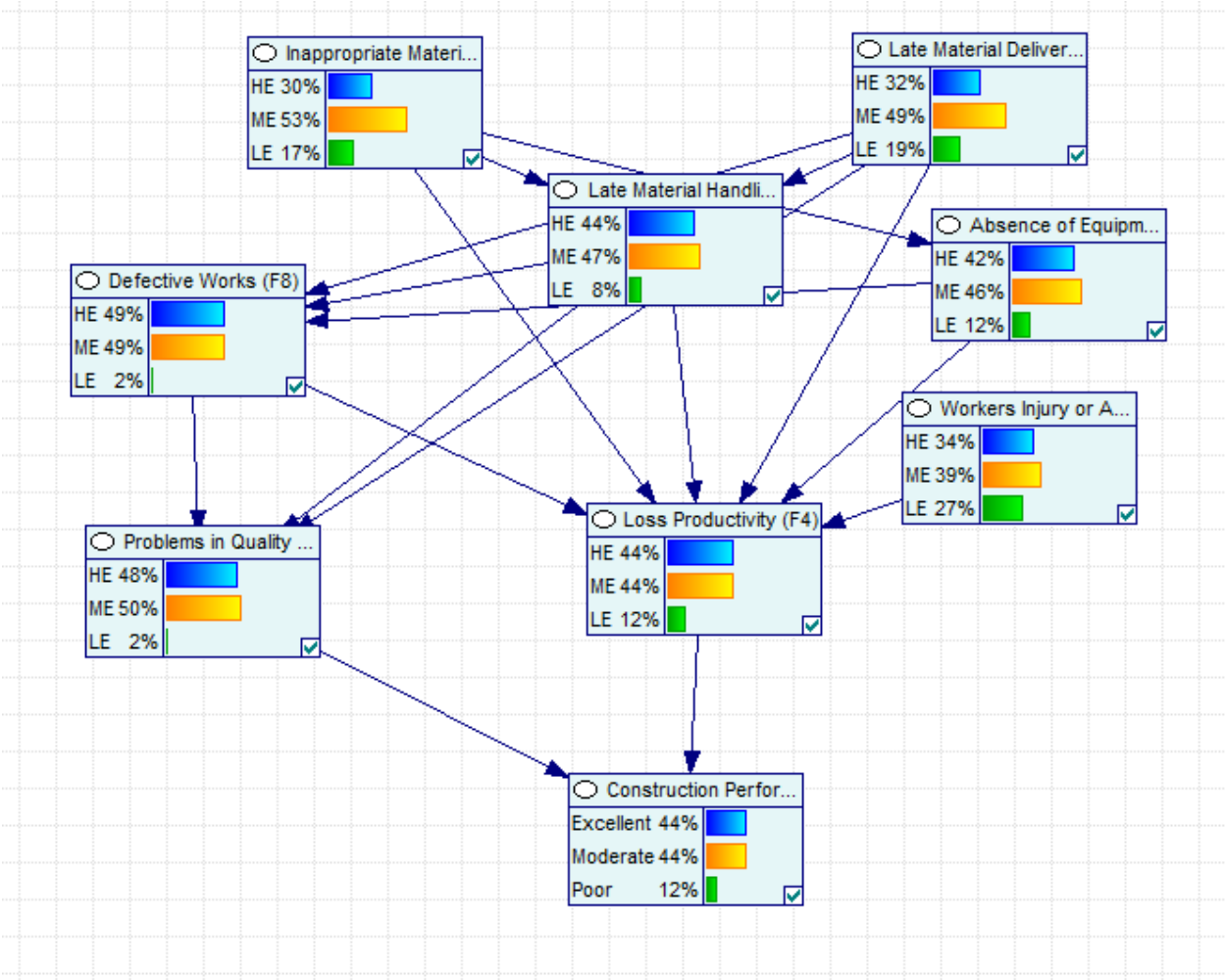


Figure 3-7. The initial BBN development with probability of occurrence of each factors for small companies

**Parameter Learning Process**

In order to fully specify and represent the joint probability distribution in a BBN model, parameter learning process is required. In the GeNIe Ver.2.0 application, the parameter learning process function is included. Through this function, the conditional probabilities of each node were automatically generated. Sometimes, parameter learning process can be substituted by expert opinions (Luu et al. 2009).

Applying the parameter learning process to initially developed BBN models, the probability values were re-generated as shown in Figure 3-8 and Figure 3-9 for large and small companies, respectively.

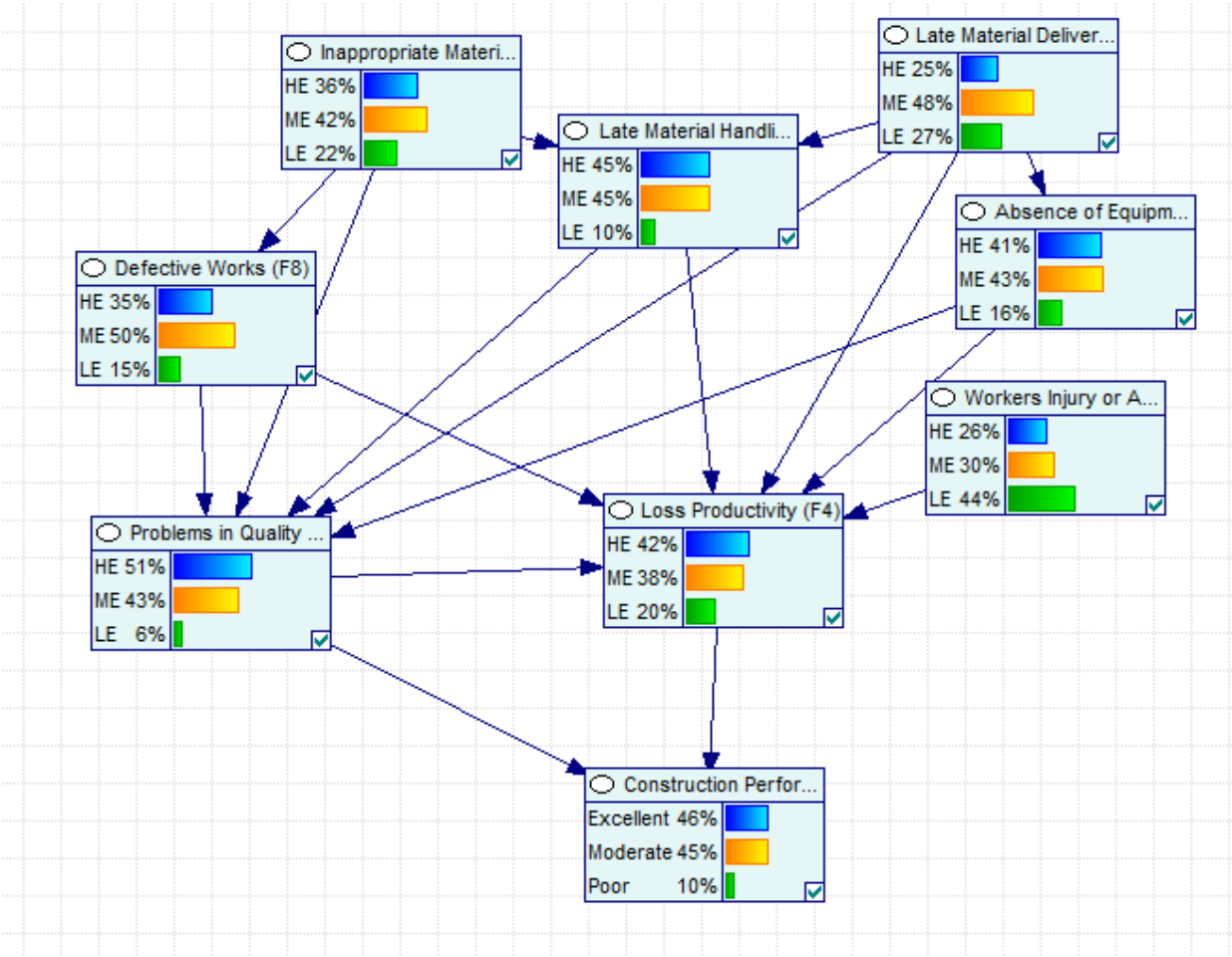


Figure 3-8. The BBN model after parameter learning process for large companies

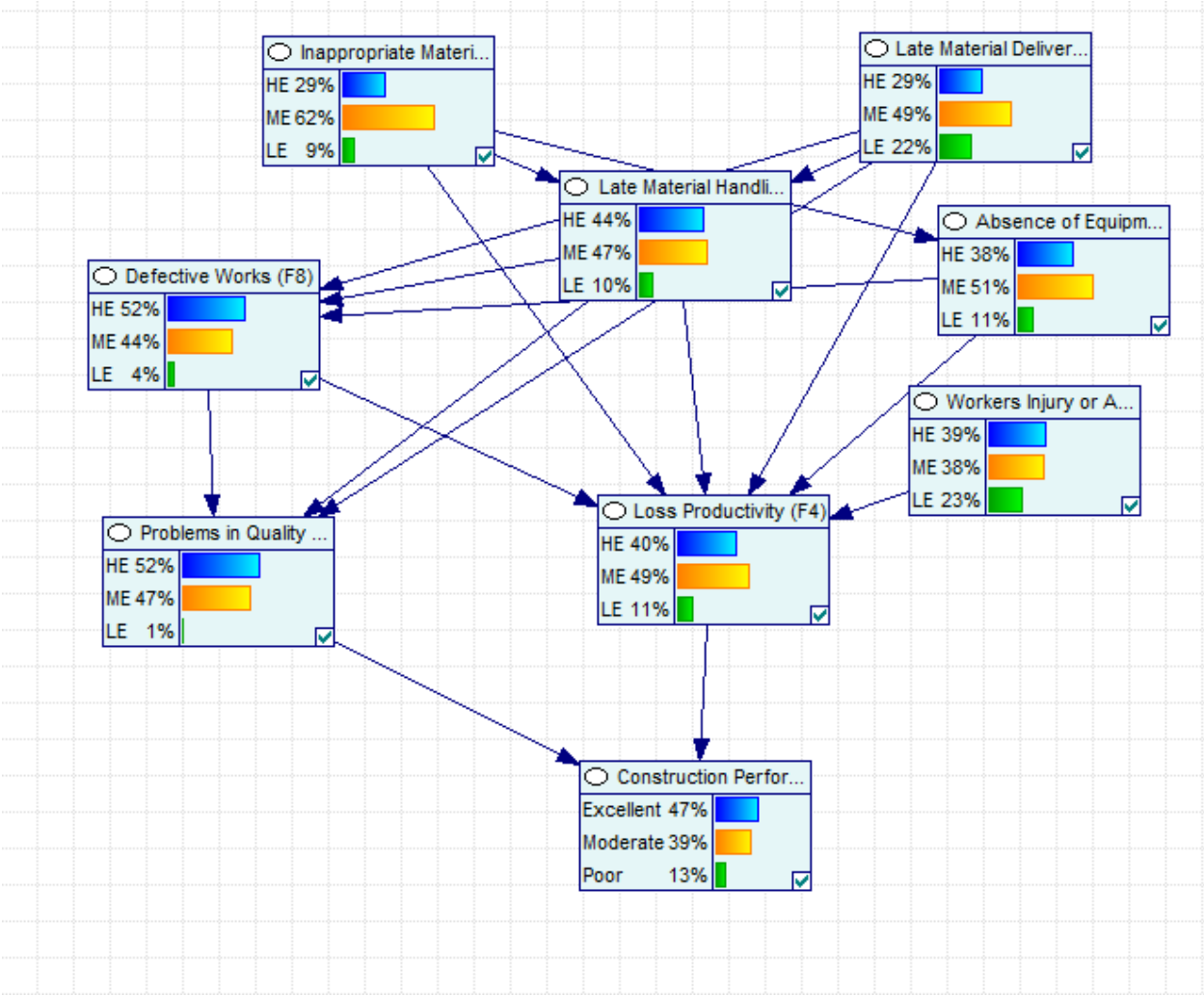


Figure 3-9. The BBN model after parameter learning process for small companies

# CHAPTER 4
# RESULTS AND ANALYSIS

## Overview

In this chapter, the evaluations of survey results are described, and the potential benefits of DATs integration are quantified with estimation of the change of construction performance occurrence probability according to the change of certain factors' occurrence probability in previously developed BBN models for large and small sizes of construction companies.

## Evaluations of the Survey

The dynamic survey form was created for acquiring respondents' consistent answers. For this study, the developed dynamic survey forms were sent to two hundred and twenty five respondents randomly selected from the lists of 1000 Top Construction Company of 2009 provided by Construction Association of Korea. And seventy three responses were received, representing a response rate of 32%.

Through the part 1 of survey questionnaire, the respondents working years, the types of construction specialties of respondents were identified as shown in Figure 4-1 and Figure 4-2, respectively.

Furthermore, the responded companies were divided into large and small sized companies based on the respondents' annual revenue for past years. The large size companies are classified that the companies' annual revenue for past year were over $100 million. And, the companies which the annual revenue is below than $100 million were organized as small size companies in this study. Of the seventy three answered respondents, twenty nine companies were classified as large size company, and forty four responses were considered as small size company as shown Figure 4-3.

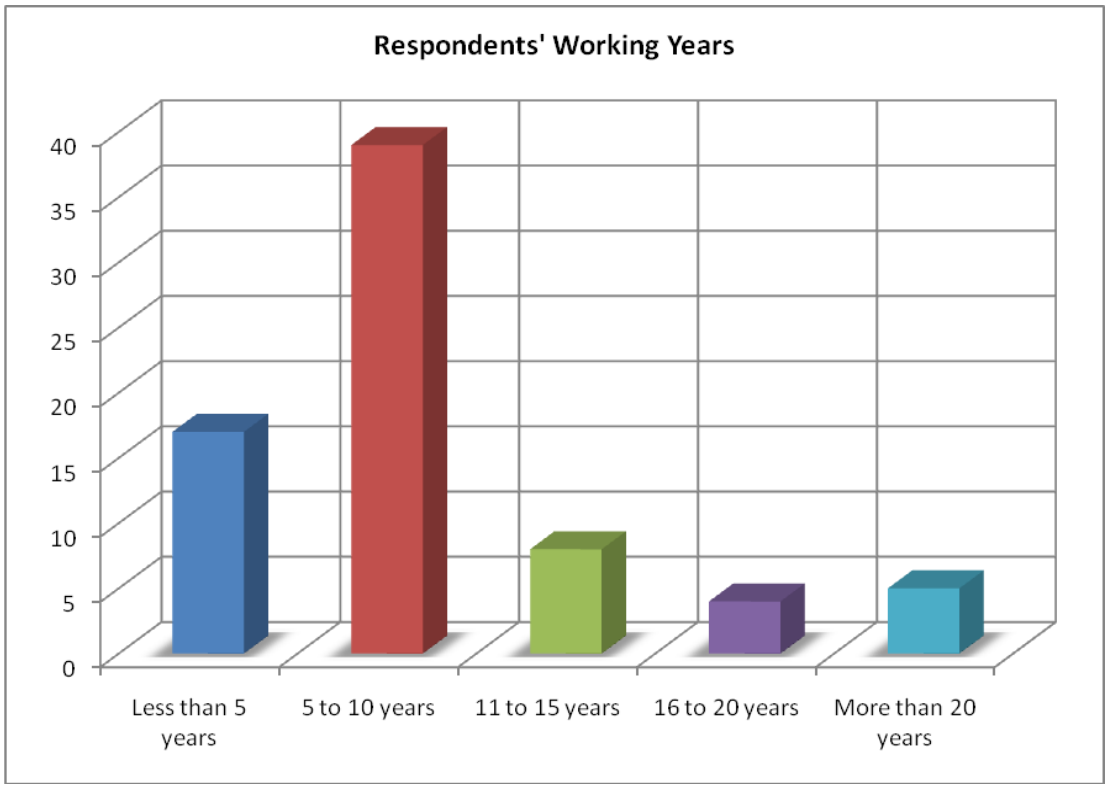


Figure 4-1. The distribution of respondents' working years

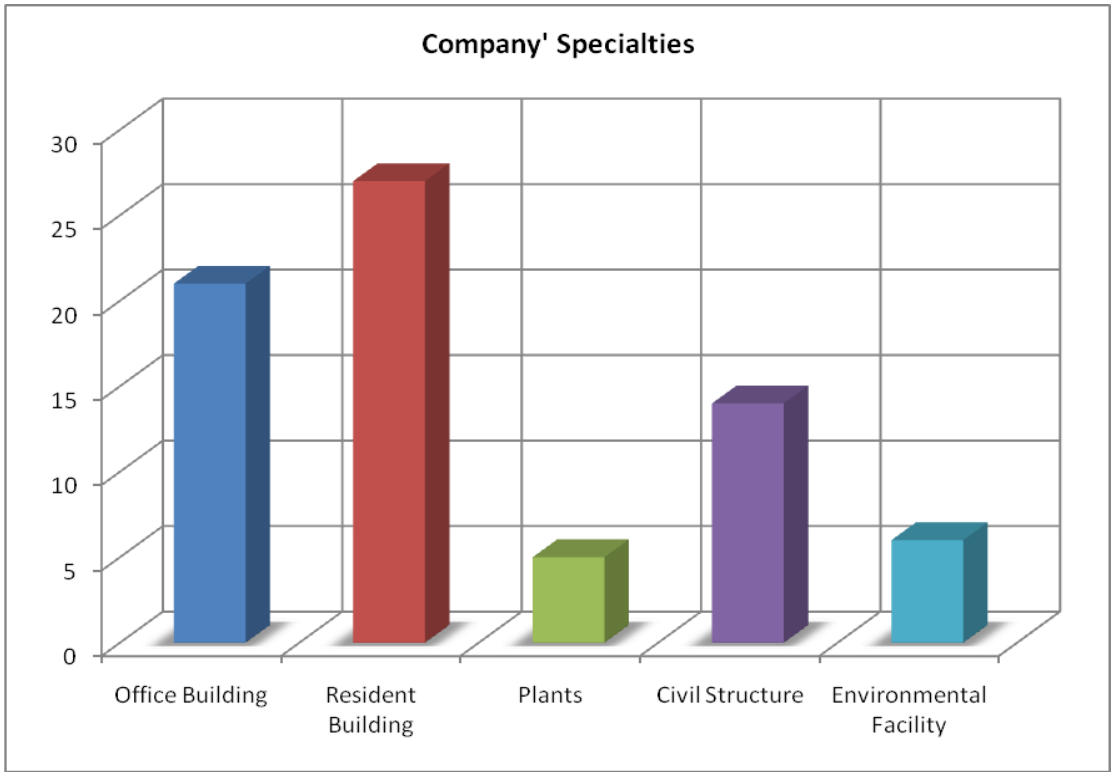


Figure 4-2. The distribution of companies' specialties

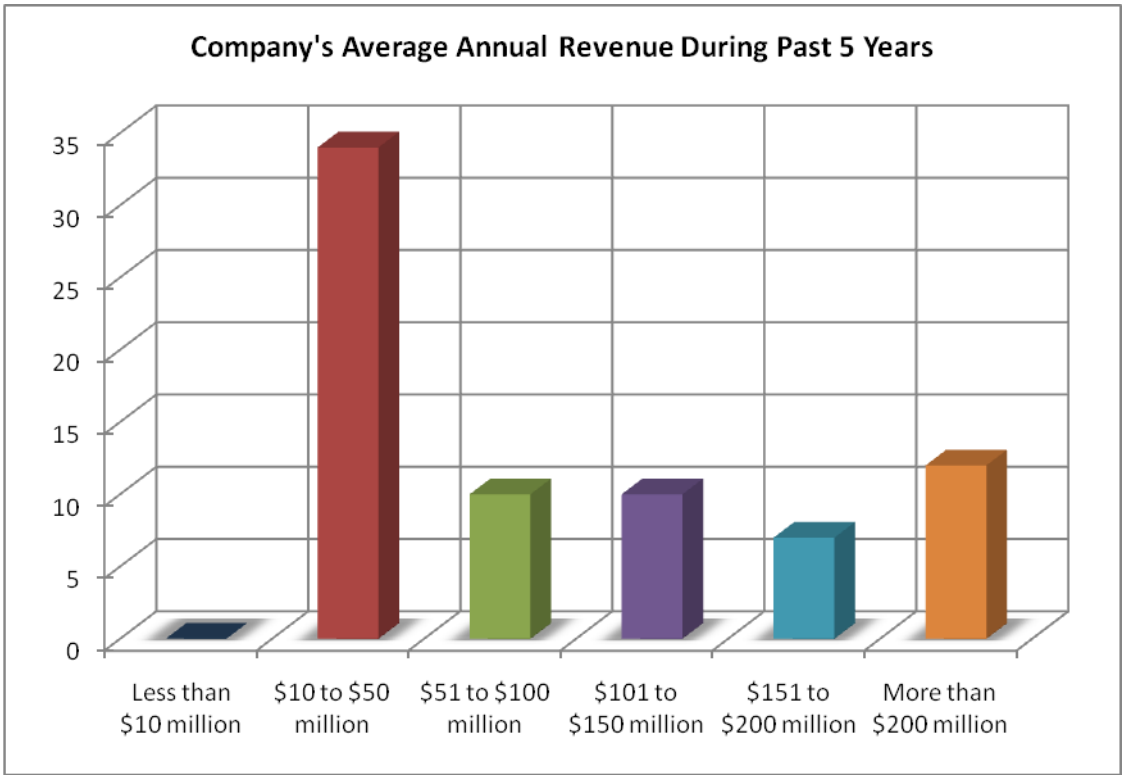


Figure 4-3. The companies' average annual revenue during past 5 years

In the part 3 of survey questionnaire, in order to evaluate the current DATs use, respondents were asked to choose all DATs that are implemented on their projects. By the evaluation of the survey results, it is observed that twenty eight of twenty nine large companies (97%) are using automated DATs on their projects. On the other hand, thirty two respondents of forty four small companies (73%) answered that automated DATs were implemented for their projects as shown in Figure 4-4.

The types of implemented DATs in large and small construction companies are summarized in Figure 4-5 and Figure 4-6, respectively. More specifically, RFID systems and RFID+USN systems are mostly adopted in large construction companies. On the other hand, PDA systems and RFID systems are predominant in small companies based on the survey results.

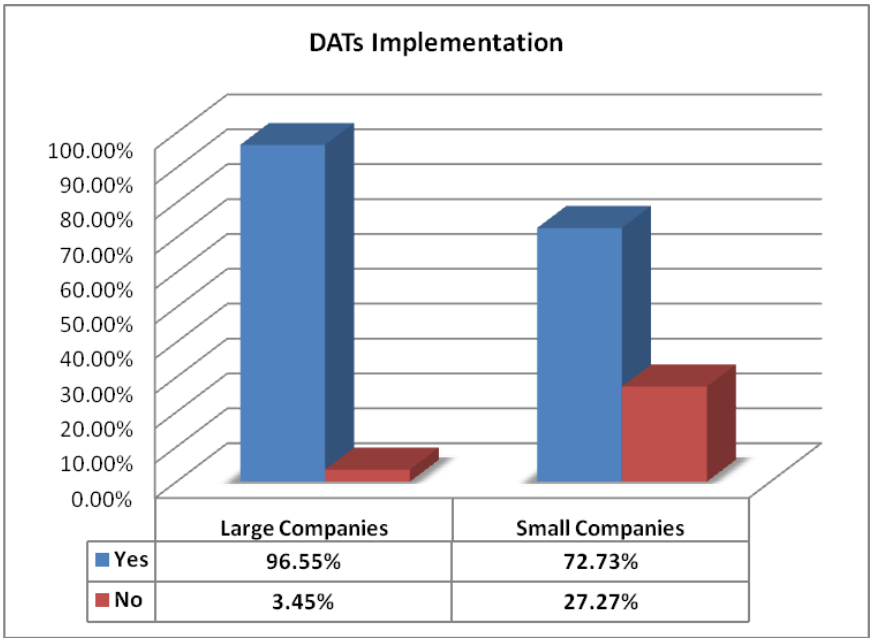


Figure 4-4. The implementaion of DATs on the respondents' construction projects

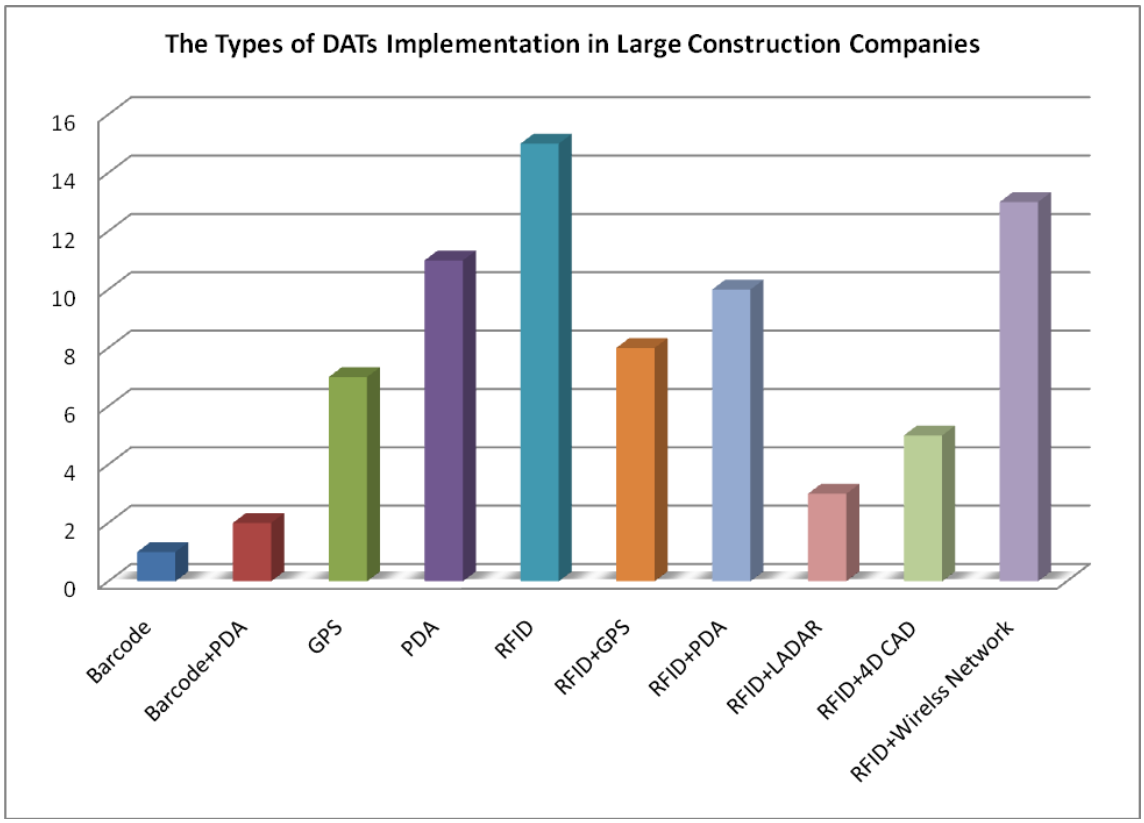


Figure 4-5. The types of implementaed DATs in large construction companies

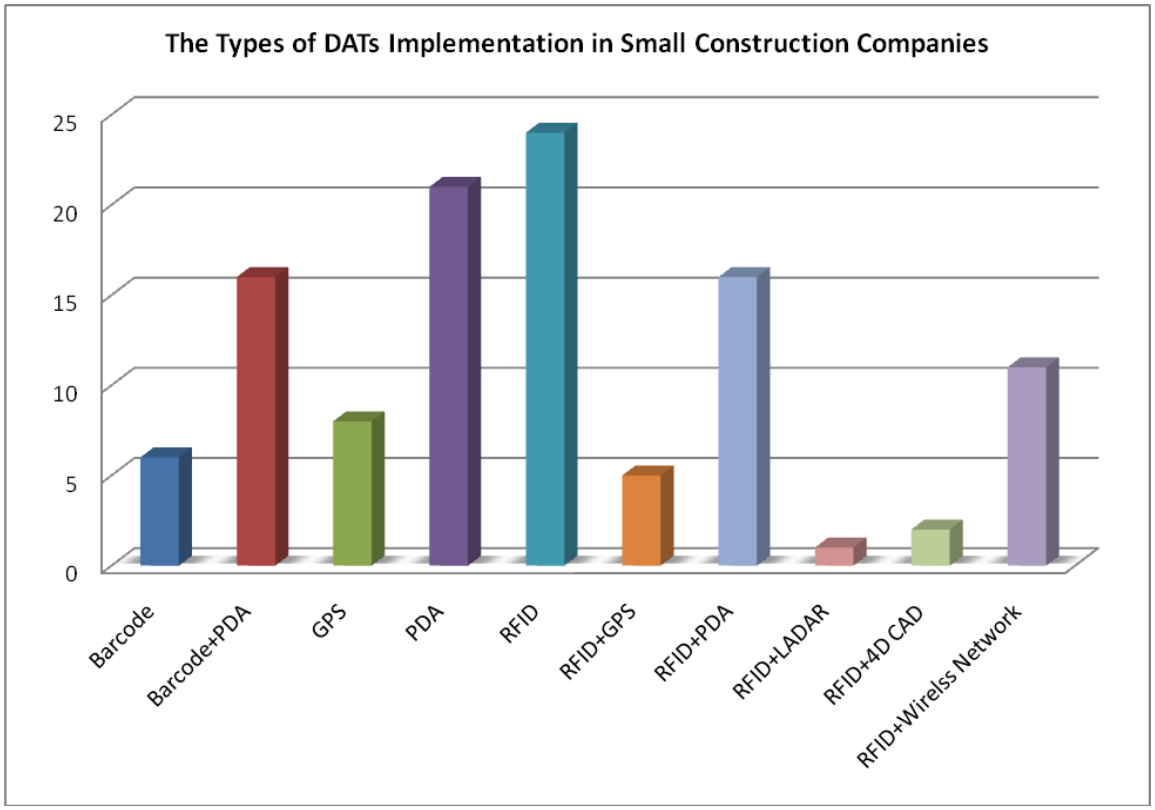


Figure 4-6. The types of implementaed DATs in small construction companies

In large and small construction companies, individual RFID systems are mostly implemented for their projects. In the second place, RFID integrations with other DATs and PDA systems are widely used in the projects. Based on these yielded results, the fact that RFID system and integration of RFID with other DATs are popular in current construction industry was validated.

Furthermore, the noticeable finding that PDA systems are widely accepted in large and small construction companies was identified in this study. Especially, of thirteen respondents who answered that any DATs are not used in the projects, nine respondents (69%) answered that they are considering PDA integration system for their projects, four respondents (31%) chose RFID integration systems for their projects. With these evaluations, it can be inferred that the integration of PDA systems also have

a great potential to be developed in addition to the RFID integration systems. One of the main reasons why PDA integration system is being considered to be implemented in construction project is that widespread smart phone uses. Current smart phone technologies are capable to replace the PDA functions. Moreover, the explosive increasing smart phone uses may lead to reduce the equipment's cost and it result in the PDA DATs development in construction industry.

However, the remarkable difference of the types of DATs implementation between large and small companies is observed through the evaluation of survey results. That is the highly use rate of barcode system in small construction companies. Twenty two (69%) of thirty two respondents in small companies answered that individual barcode systems or integration barcode systems are still using on their projects, whereas three (11%) of twenty eight respondents in large companies answered that barcode systems are adopted on their projects.

Due to the high installation cost of RFID integration systems, the barcode systems are still prevailed in small construction companies. In other words, barcode systems may be more beneficial for some construction projects of small companies in terms of the costs, rather than using RFID systems.

**Re-Organization of Dataset for Bayesian Belief Network (BBN) Analysis**

In order to identify and quantify the potential benefits of DATs integration in large and small construction companies using BBN analysis, the dataset were re-organized depending on the construction specialties in large and small companies. Specifically, the companies, which are using only individual DATs on their projects, were selected for quantifying the benefits of DATs integration. Of twenty eight respondents in large companies, eleven answered that they are using individual DATs, whereas of thirty two

respondents in small companies, nineteen answered for individual DATs implementation. The summarized re-organizations of results are described in Table 4-1.

Table 4-1. The summary of re-organizing dataset for BBN analysis

| Size of companies | Specialties | Implemented individual DATs | Number of respondents |
|---|---|---|---|
| Large companies | Resident building | RFID system | 5 |
| | Civil structure | GPS system | 3 |
| | Office building | RFID system | 3 |
| Small companies | Office building | RFID system | 7 |
| | Resident building | PDA system | 6 |
| | Office building | PDA system | 4 |
| | Civil structure | GPS system | 2 |

With these re-organizing dataset, the averaged negative factors' occurrence probabilities were re-developed for BBN analysis. However, due to the insufficient data answers caused by small numbers of respondents, certain negative factors' occurrence probabilities were not fully developed. As a result, total two (one for large companies and one for small companies specialized in resident building) BBN models were proposed in this study.

**BBN Analysis for Large Companies Specialized in Resident Building**

According to Table 4-1, five respondents indicated that individual RFID systems are implemented on resident building projects in large companies. The averaged negative factors' occurrence probabilities for five respondents were identified as shown in Table 4-2. In order to identify the differences of occurrence probabilities between five respondents and all respondents in large companies, the estimated values of probabilities from Table 3-4 were also shown in Table 4-2.

In the new developed negative factors' occurrence probabilities for five respondents, it was identified that F6 model variable, problems in quality management,

is mostly occurred in resident building project of large companies implemented individual RFID system. On the other hand, all respondents in large companies answered that F4 model variable, loss productivity due to the waiting time for work order, is mostly occurred on their project.

Table 4-2. The averaged occurrence probabilities of negative factors in large companies specialized in resident building with individual RFID DATs (%)

| Model Variables | Average of five respondents | | | Average of all respondents in large companies (from Table 3-4) | | |
|---|---|---|---|---|---|---|
| | High Effect (HE) | Medium Effect (ME) | Low Effect (LE) | High Effect (HE) | Medium Effect (ME) | Low Effect (LE) |
| F1 | 22.1 | 39.8 | 38.1 | 32.5 | 41.7 | 25.8 |
| F2 | 26.4 | 62.6 | 11.0 | 37.2 | 60.8 | 2.0 |
| F3 | 35.7 | 20.6 | 43.7 | 25.9 | 50.4 | 23.7 |
| F4 | 38.2 | 41.5 | 20.3 | 39.2 | 44.5 | 16.3 |
| F5 | 23.1 | 22.5 | 54.4 | 12.4 | 22.9 | 64.7 |
| F6 | 49.2 | 31.9 | 18.9 | 37.2 | 36.4 | 26.4 |
| F7 | 23.8 | 32.4 | 43.8 | 24.9 | 33.6 | 41.5 |
| F8 | 30.7 | 38.1 | 31.2 | 28.6 | 39.5 | 31.9 |

These new developed factors' probabilities were input to the previously developed BBN model for large companies shown in Figure 3-6. After new data input procedure, parameter learning process was conducted to develop conditional probabilities of all factors for new BBN model.

New BBN model for large companies specialized in resident building with implementation of individual RFID systems is developed as shown Figure 4-7.

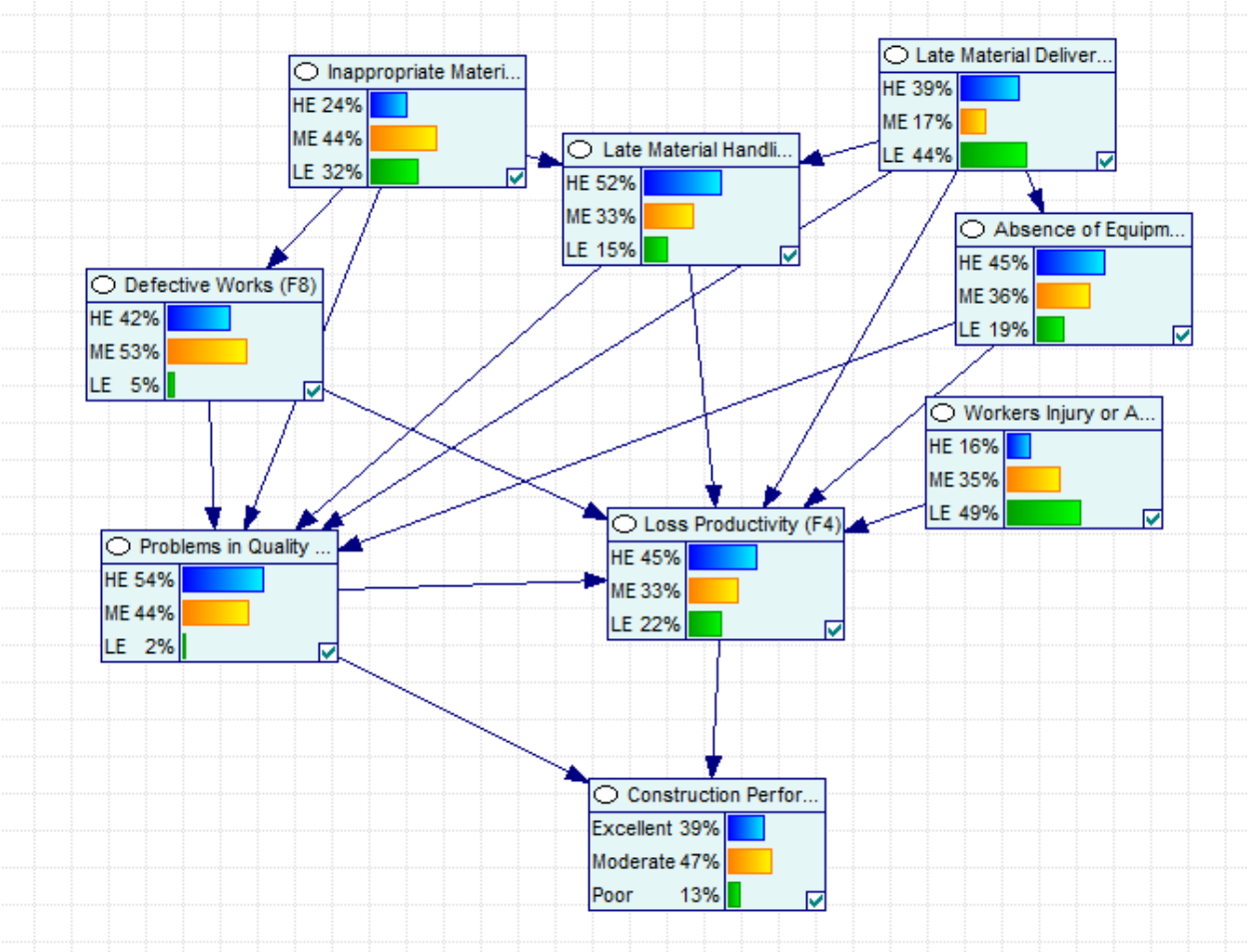


Figure 4-7. The new developed BBN model for five respondents' large companies specialized in resident building with individual RFID systems implementation

In order to quantify the potential benefits of DATs integration with new developed model, two DATs integrations systems were suggested to this model based on the literature reviews. According to the previous studies, this study assumes that the RFID+4D CAD integration is ideal for quality management, and RFID+USN is beneficial for reducing waiting time.

With these assumptions, the benefits of RFID+4D CAD DATs implementation in this case was estimated as normalizing the value of LE (low effect) to 100% in factor of problems in quality management (F6 model variable), as shown in Figure 4-8.

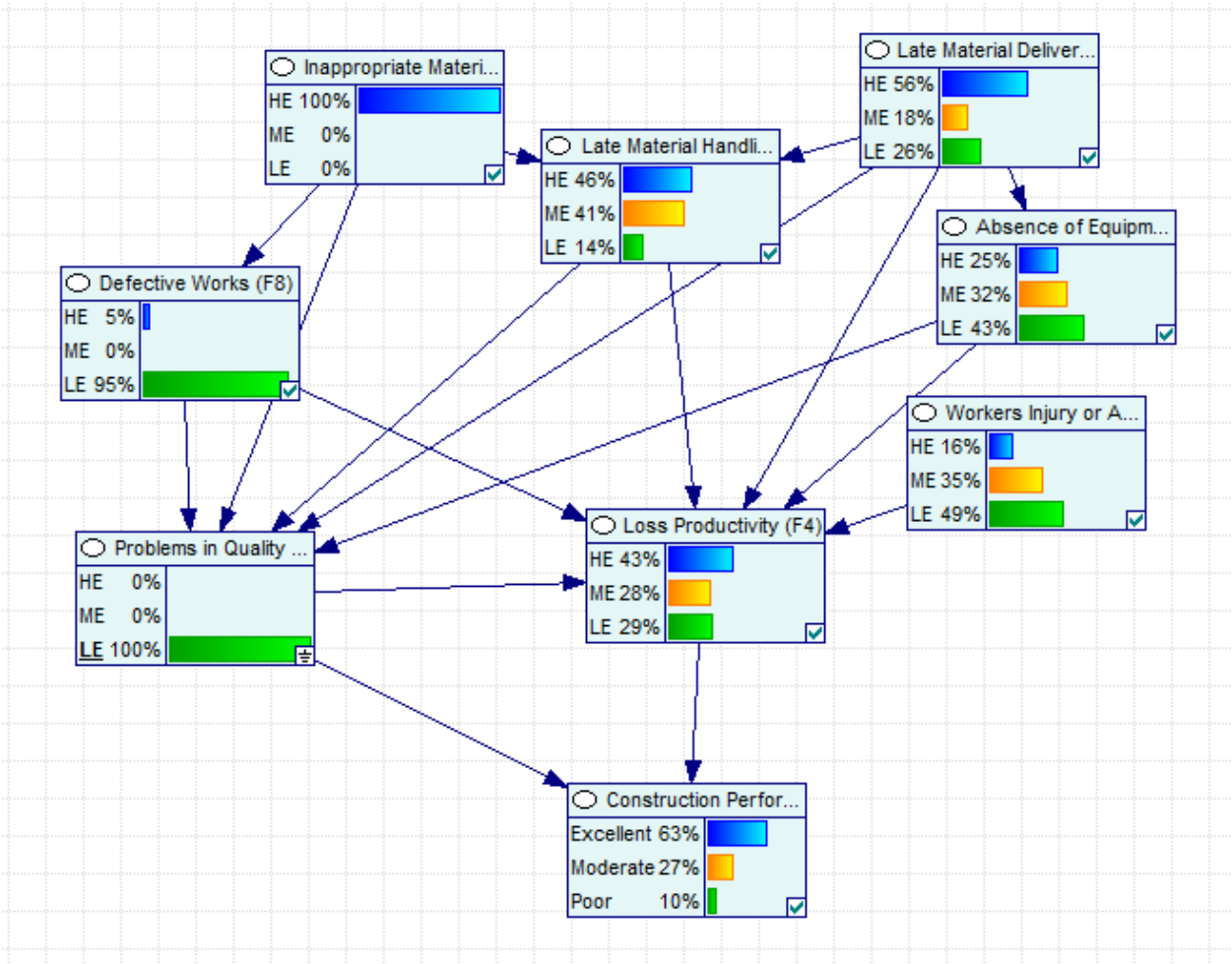


Figure 4-8. The change of F6 factor's probability in the BBN analysis for five respondents' large companies specialized in resident building with individual RFID systems implementation

As normalizing the LE value in F6 factor to 100%, the excellent probability of construction performance was increased to 63% from 39%. Based on this BBN model, about 24% increasing performance is expected if five companies adopt RFID+4D CAD DATs on their project. This increased probability of construction performance was

calculated based on the conditional probabilities of all factors with conditionally set up of LE of 100%.

In the similar way, the benefits of RFID+USN DATs were estimated as shown Figure 4-9.

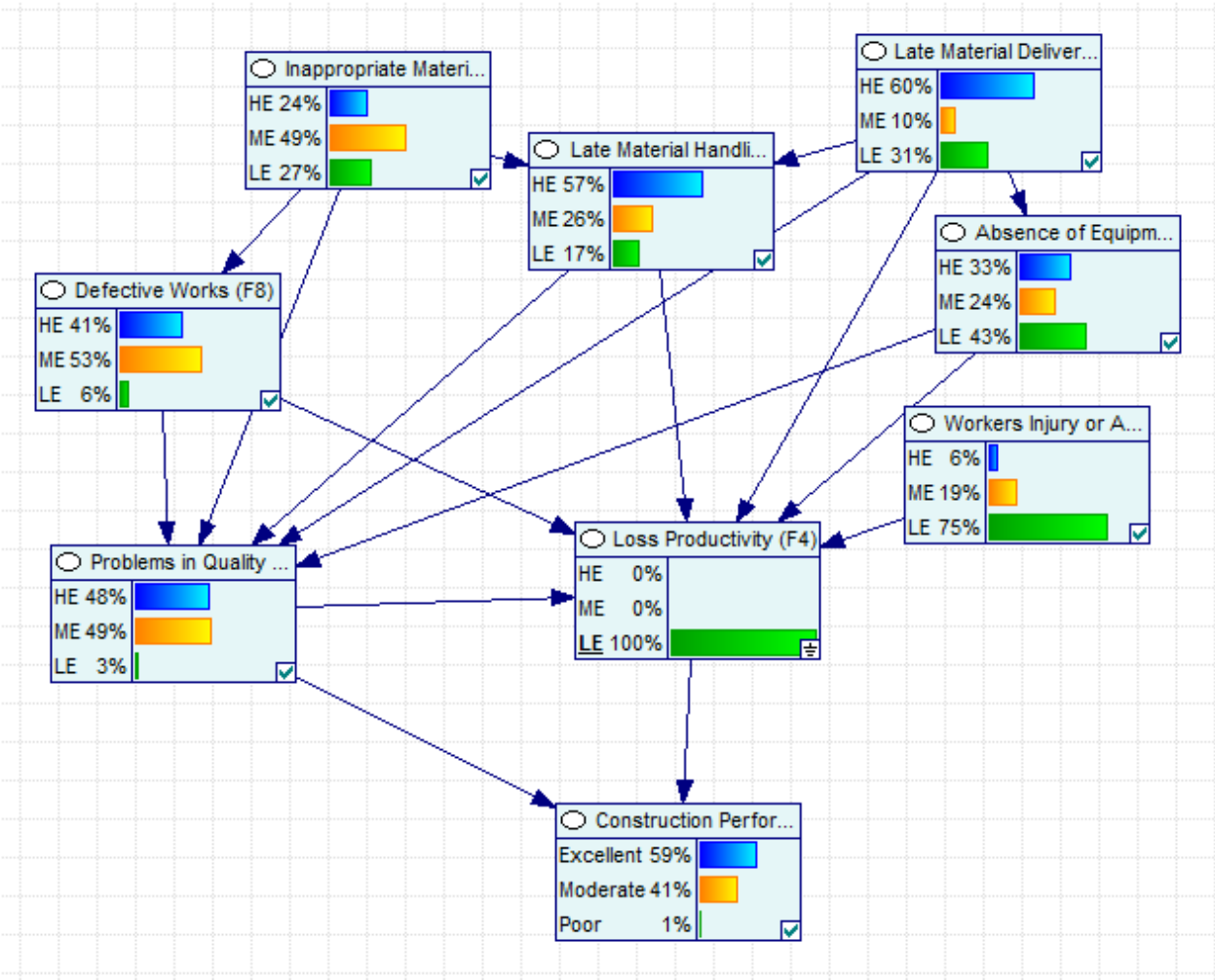


Figure 4-9. The change of F4 factor's probability in the BBN analysis for five respondents' large companies specialized in resident building with individual RFID systems implementation

In this BBN model, the probability of excellent construction performance is increased to 59%, and the probability of poor construction performance is reduced to 1%.

In comparison with the BBN model for implemented RFID+4D CAD system, the probability of poor performance was dramatically reduced in this BBN model. Therefore, it can be concluded that the minimizing the effect of F4 factor with RFID+USN implementation will greatly reduce about 10% of poor construction performance in residential building construction in large size companies.

**BBN Analysis for Small Companies Specialized in Resident Building**

According to Table 4-1, six respondents answered that individual PDA systems are implemented on resident building projects in small companies. In the same way in above, the averaged negative factors' occurrence probabilities for six respondents were identified as shown in Table 4-3.

Table 4-3. The averaged occurrence probabilities of negative factors in small companies specialized in resident building with individual PDA DATs (%)

| Model Variables | Average of five respondents | | | Average of all respondents in small companies (from Table 3-5) | | |
|---|---|---|---|---|---|---|
| | High Effect (HE) | Medium Effect (ME) | Low Effect (LE) | High Effect (HE) | Medium Effect (ME) | Low Effect (LE) |
| F1 | 35.1 | 29.4 | 35.5 | 29.9 | 52.6 | 17.5 |
| F2 | 27.6 | 31.5 | 40.9 | 22.7 | 53.7 | 23.6 |
| F3 | 33.9 | 39.4 | 26.7 | 32.1 | 49.2 | 18.7 |
| F4 | 15.2 | 51.0 | 33.8 | 19.5 | 62.7 | 17.8 |
| F5 | 29.9 | 31.8 | 38.3 | 22.4 | 36.1 | 41.5 |
| F6 | 10.3 | 21.4 | 68.3 | 22.4 | 57.6 | 20.0 |
| F7 | 29.4 | 28.4 | 42.2 | 33.9 | 39.2 | 26.9 |
| F8 | 18.6 | 34.7 | 46.7 | 29.5 | 41.4 | 29.1 |

In the new developed negative factors' occurrence probabilities for six respondents in small companies, it was identified that F1 model variable, inappropriate material handling on layout, is mostly occurred in resident building project of large companies implemented individual PDA system. Whereas, the occurrence probability of F6 model variable, problems in quality management, was estimated at low level.

With these evaluations, it can be inferred that the PDA systems are beneficial for quality management, especially for small companies.

With the same way on previous section, these new factors' probabilities were applied to the BBN model for small companies shown in Figure 3-7. After the process of parameter learning, the conditional probabilities of all factors for new BBN model were developed.

New BBN model for small companies specialized in resident building with implementation of individual PDA systems is developed as shown Figure 4-10.

In order to quantify the potential benefits of DATs integration with new developed BBN model for small companies implemented with individual PDA system, RFID+PDA DATs integration was suggested to this model. Based on the literature reviews in the chapter 2, this study assumes that the RFID+PDA integration is ideal for material and labor management.

With the assumptions, the benefits of RFID+PDA DATs implementation in this case was estimated as normalizing the value of LE (low effect) to 100% in the factor of inappropriate material handling on layout (F1 model variable), and in the factor of late material handling from layout to specific jot site (F2 model variable), as shown in Figure 4-11.

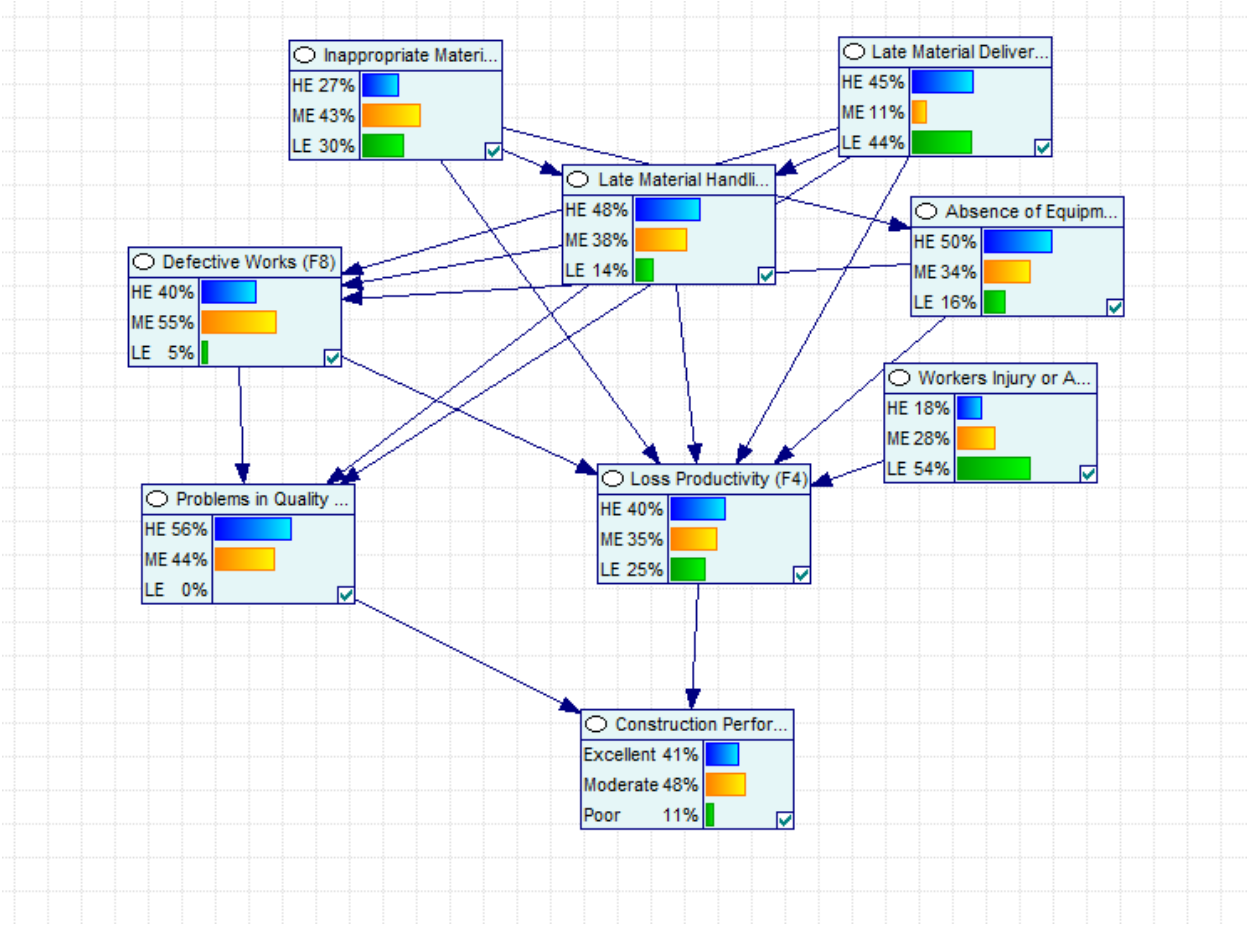


Figure 4-10. The new developed BBN model for six respondents' small companies specialized in resident building with individual PDA systems implementation

As mentioned above, RFID+PDA integration system is also beneficial for the labor management on construction sites. Recently, RFID+PDA systems are applied to the workers' safety management practices. Therefore, another assumption that is the negative effect of workers' injury or accident (F7 model variable) can be minimized with the implementation of RFID+PDA integration is proposed for this study.

In addition to the normalizing of F1 and F2 factors at low effect level, the F7 factor is also normalized at low effect level to identify the maximum potential benefits of RFID+PDA integration in small companies. The result is shown in Figure 4-12.

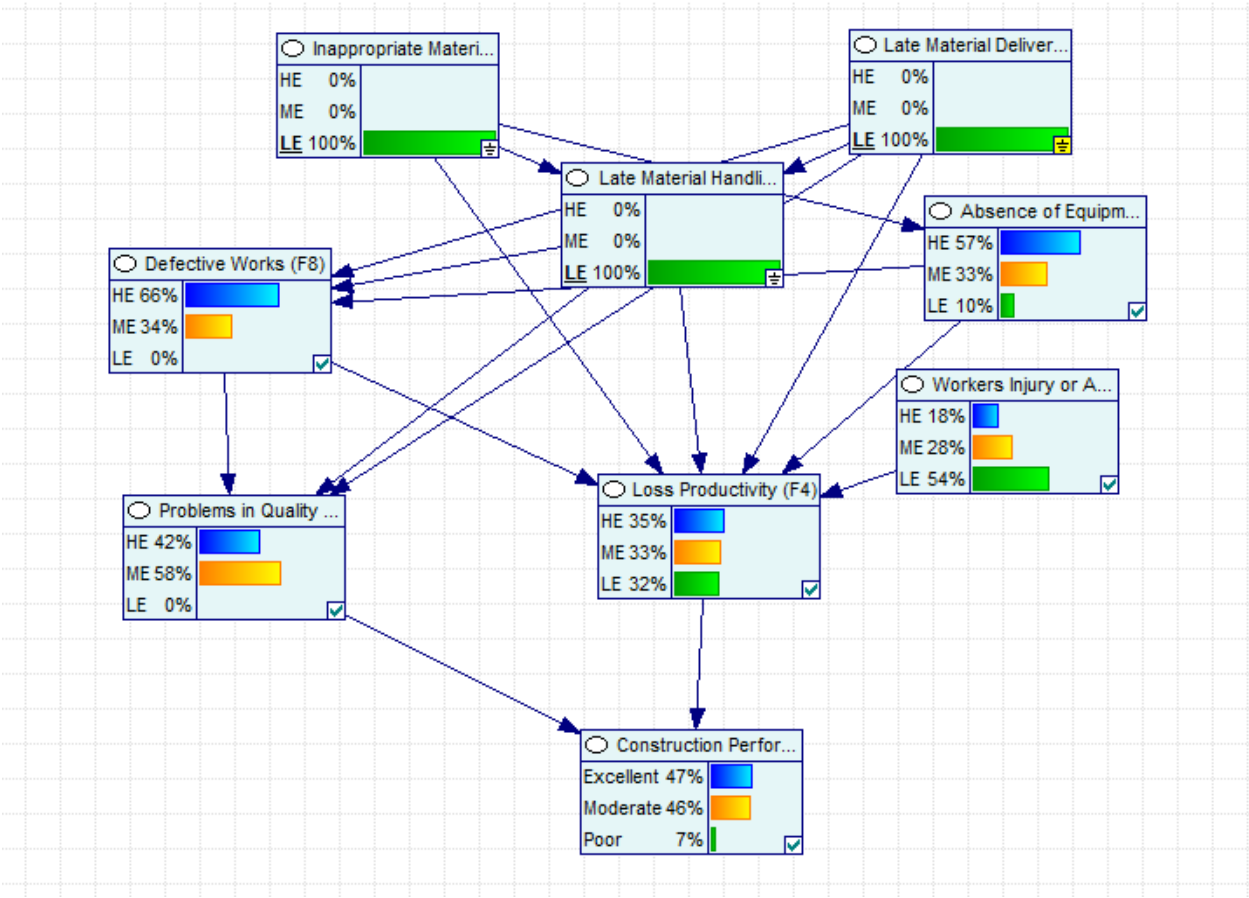


Figure 4-11. The change of F1 and F2 factors' probability in the BBN analysis for six respondents' small companies specialized in resident building with individual PDA systems implementation

By adopting RFID+PDA integration in this BBN model for small companies, the probability of excellent construction performance was increased to 47% from 41%. Moreover, it was observed that the probability of poor performance was not relatively improved.

However, after the normalizing F7 factors with RFID+PDA integration, the probabilities were dramatically changed. First of all, the probability of excellent performance was 5% more increased. And, the probability of poor performance of 2% was estimated in the BBN model.

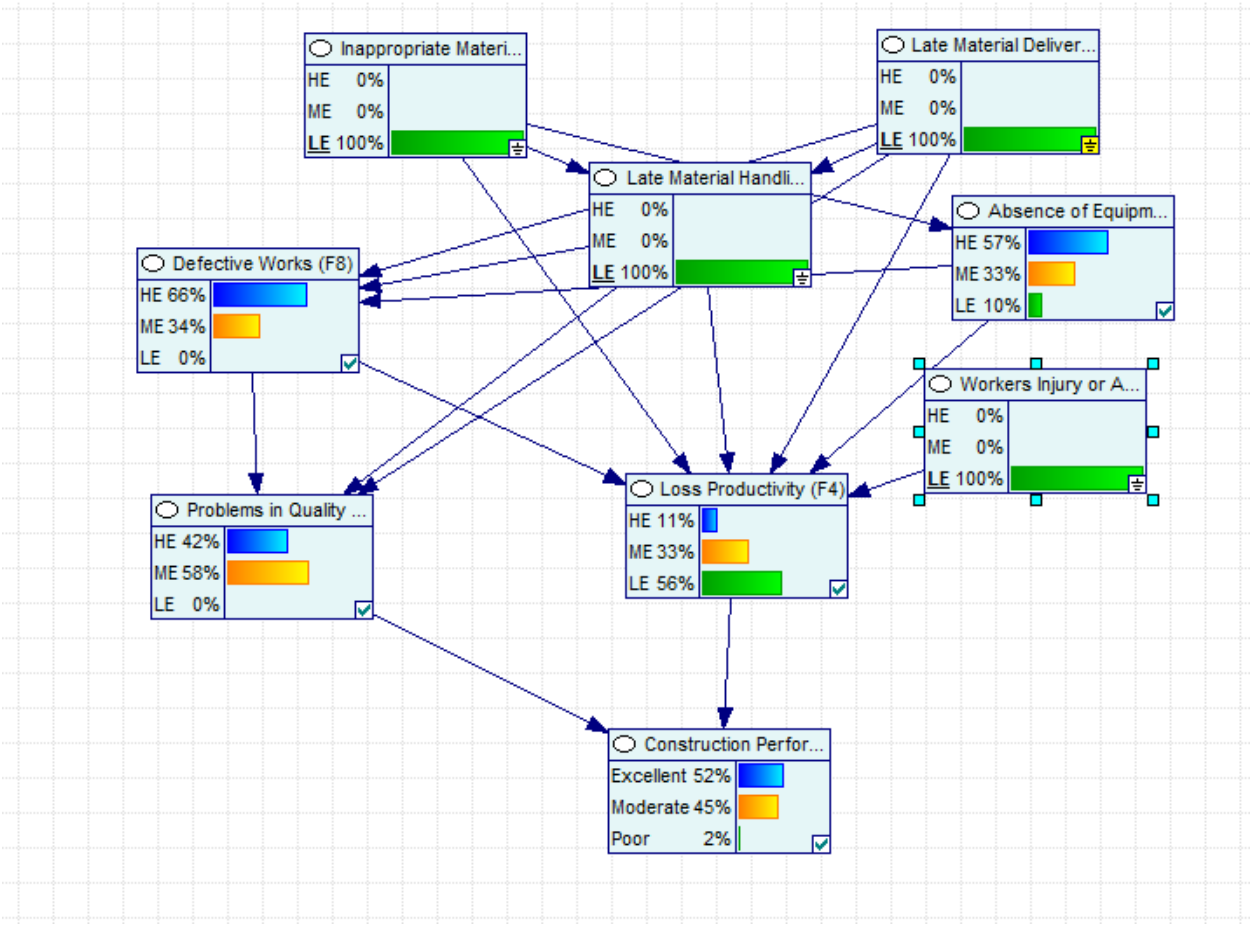


Figure 4-12. The change of F1, F2, and F7 factors' probability in the BBN analysis for six respondents' small companies specialized in resident building with individual PDA systems implementation

# CHAPTER 5
# CONCLUSIONS

The purpose of this study is to identify current automated data acquisition techniques (DATs) and the integration of DATs for construction data management. Furthermore, through Bayesian belief networks (BBNs) analysis, the potential benefits of DATs integration are evaluated and quantified.

For these objectives of the study, previously published studies according to the types of DATs were reviewed in detail. And, in order to identify current trends of DATs implementation in construction industry, survey was conducted.

Based on the detailed literature reviews, this study finds that barcode, RFID, PDA, and GPS systems were implemented in construction industry during past decades. However, these individual DATs systems have own limitations and disadvantages to improve construction data management practices. In order to overcome these limitations and disadvantages of individual DATs, the integrations of DATs are widely accepted in construction industry. Moreover, many studies indicated that the integrations of DATs, especially integration RFID with other DATs, have capability to enhance the data management.

Specifically, the numerous data generated from construction activities are valuable resources to track and monitor construction performances. Also, adequate construction data management is directly related to construction productivity, construction schedule, and cost analysis. Although construction data management is significant for overall construction activities, many construction companies still adopt individual DATs for their projects due to the uncertainties and high installation costs of integration of DATs.

Under these conditions, this study attempted to quantify the potential benefits of integration of DATs in real construction industry using BBNs analysis. BBN model is supportive tool for decision making process with graphical outputs of cause and effects among the factors.

In this study, one of the representative computer algorithm applications for BBN analysis, GeNIe Ver. 2.0 was used for BBN analysis.

For the well development of BBN model, dynamic survey form, which is enabled for respondents to input consistent answers in the suggested questions, was created. Throughout the literature review, eight of the negative factors that affect construction data management were predefined. The predefined negative factors were provided to survey respondents to determine their occurrence probabilities on their past projects. In the next step, respondents were asked to specify the relationships among the factors.

With the collected dataset, the frequency of the specified relationships of factors was calculated. The top ranked fifteen relationships were selected to develop cause and effects relationships for the BBN model.

Based on the determined relationships among the factors, two BBN models were initially created for large and small construction companies. Specifically, the companies that have more than $100 million of average annual revenue for the preceding 5 years which were classified as large companies, and companies that have less than $100 million of average annual revenue, which were considered as small companies.

For the next step, the companies that had implemented individual DATs on their project were identified depending on their size. A total of seven companies were identified as the companies which are using individual DATs on their projects. Of the

seven companies, one large and one small company were selected to quantify the potential benefits of the integration DATs through BBN analysis.

In the BBN analysis, the benefits of integration of DATs for construction data management were estimated by calculating the probability of excellent construction performance while changing the factors' occurrence probabilities.

In the large companies for high rise residential building construction which are implemented with individual RFID systems, two integrations of DATs such as RFID+4D CAD and RFID+USN were applied to the BBN model to estimate the potential benefit of integrated DATs for each. The results of the BBN analysis are shown in Figure 5-1.

With these results from the BBN model, it can be concluded that the integration of DATs implementation in large companies for high rise building construction can improve the construction data management resulting in a 20 - 24% increased construction performance.

The BBN model was also used to quantify the benefits for small companies constructing a high rise building with the implementation of an individual PDA system. In this BBN model, RFID+PDA integration system was applied. Based on the results shown in Figure 5-2 for the BBN analysis, it was determined that the implementation of the RFID+PDA system in small companies improves material and labor data management performance from 6-11%.

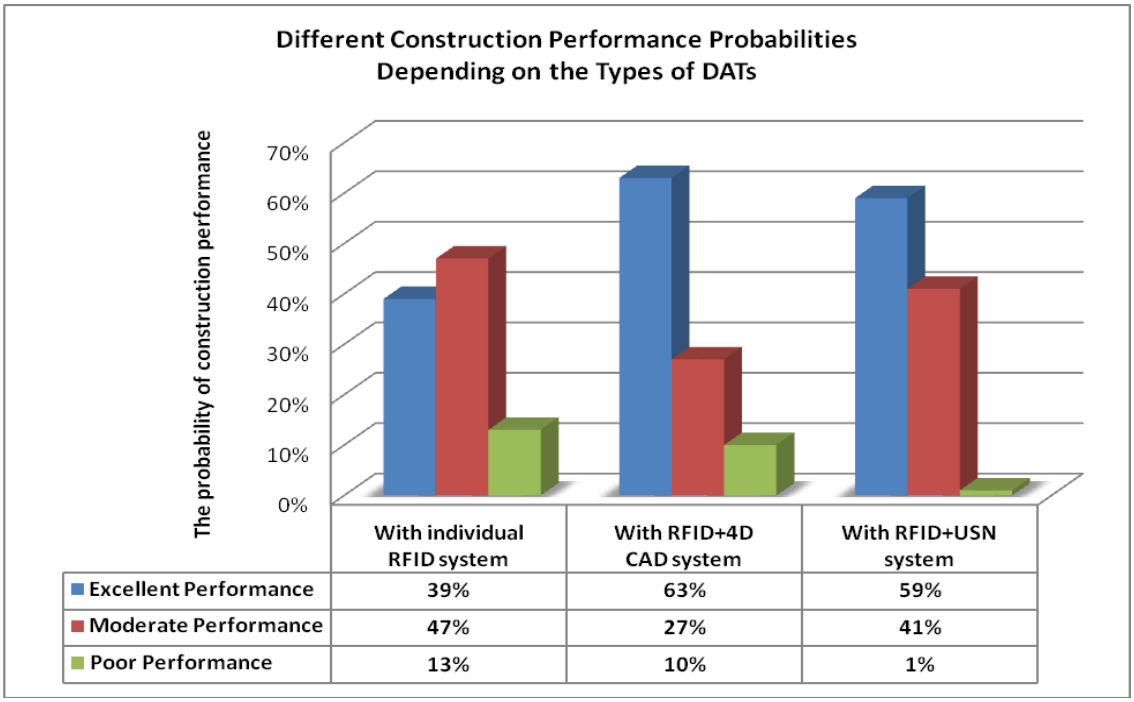


Figure 5-1. Different probabilities of construction performances depending on the applied types of DATs in large companies specializing in hig hrise residential building construction

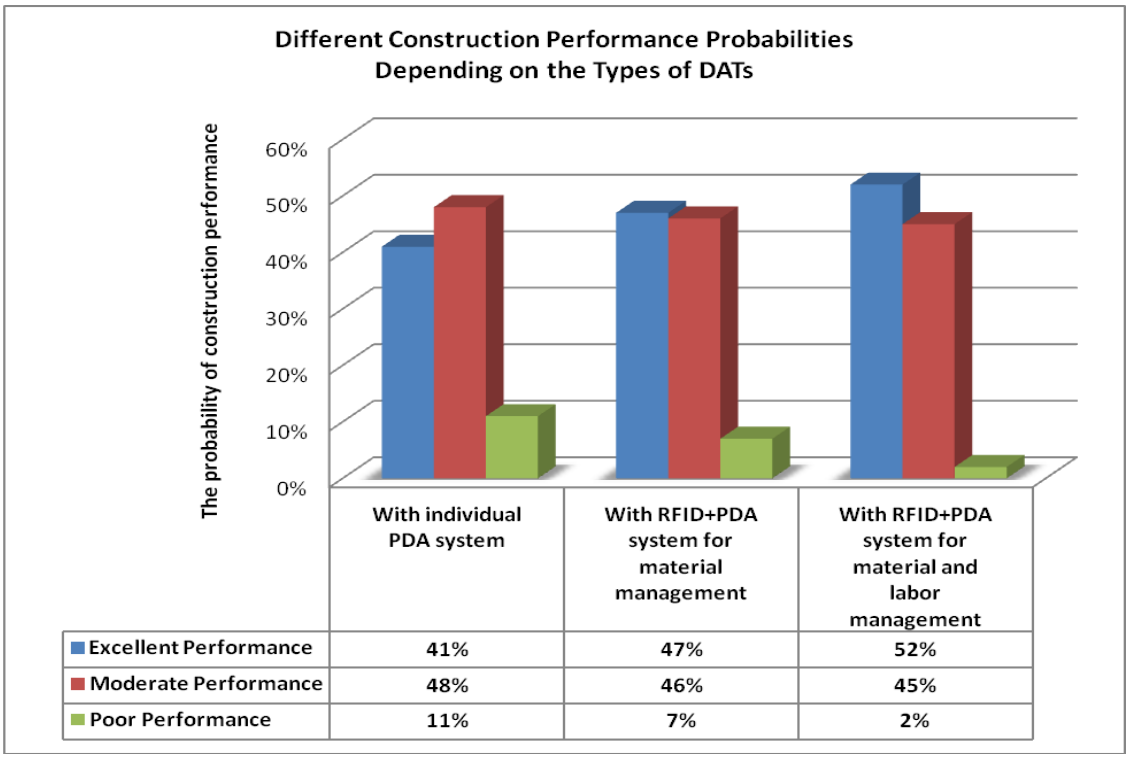


Figure 5-2. Different probabilities of construction performances depending on the applied types of DATs in small companies specializing in high rise residential building construction

In comparison with the results from BBN analysis for large companies, the range of performance improvement in small companies is relatively small. In other words, the benefits of DATs integration for construction data management in large companies are greater than in small companies. This finding is caused by the degree of relationships among the factors. As construction projects become larger, the factors affecting construction projects will become more complicated and will be impacted by many more factors. Therefore, improvement of data management in the construction industry will have a significant impact on construction project performances.

# CHAPTER 6
# DISCUSSIONS AND RECOMMENDATIONS

This study has presented a procedure to quantify the benefits of the integration of DATs in the construction industry using Bayesian belief networks (BBNs) analysis. The results of this study indicate that the integration of DATs on construction projects will have the capability of improving construction performances. The approximate range of probability for construction performance improvement was estimated to be 20 to 24% for large companies and 6 to 11% for small companies. The results of this study are similar to the findings from previous studies.

However, the procedure of this study has limitations. First, the quantified results in this study were generated from BBN analysis based on the survey results. In other words, the determined relationships among all factors were dependent on the respondents' view. Therefore, these values are not absolute values. Moreover, the identified negative factors for this study were predefined based on previous studies. Furthermore, the factors related to costs were not considered in this study.

Accordingly, future studies should be focused on the detailed evaluation of DATs integration in actual construction practices with objective data collection. In addition, other innovative procedures can be researched for identifying DATs effects on construction practices.

APPENDIX A
THE SAMPLE OF SURVEY FORM

## Survey to Identify the potential benefits of automated Data Acquisition Techniques in Construction Data Management

Thank you for allowing your time to take this survey.
This survey form was developed for academic purposes, especially for graduate study in University of Florida; therefore, any information on this survey will not be shared with others.
The main purpose of this survey is to identify the benefits of automated Data Acquisition Techniques' (DATs) implementation in construction industry. Primary DATs are RFID (Radio Frequency Identification), PDA (Personal Digital Assistance), USN (Ubiquitous Sensor Network), and GPS (Geographical Positioning System).
It is expected that the results of this survey will be valuable resources to understand DATs' benefits. The results of the survey will be provided for future references of your company. I wish your company to succeed in construction business.
I sincerely appreciate your cooperation.

먼저 설문에 참여해 주신 분께 감사드립니다.
이번 설문은 미국 University of Florida의 대학원 과정에 필요한 정보이므로 절대 타인에게 공개되지 않을 것입니다. 교육적인 목적으로만 쓰여질 것입니다.
이 설문의 주 목적은 건설 사업 분야에서 automated Data Acquisition Techniques (DATs) 사용의 이점을 확인하기 위함입니다.
대표적인 DATs 기술로는 RFID (Radio Frequency Identification), PDA (Personal Digital Assistance), USN (Ubiquitous Sensor Network), and GPS (Geographical Positioning System) 등이 있습니다.
이번 설문의 결과는 현재의 DATs 사용에 관련한 다양한 정보를 제공할 것입니다. 결과는 귀사의 발전을 위하여 설문 참여자들에게 제공 되어질 것 입니다.
귀사의 무궁한 발전을 기원합니다.
협조에 진심으로 감사를 드립니다.

Sincerely
JINTAEK OCK

## Direction

This survey form consists of four part with nine questions. The approximate time is about 15 minute.
Please read the direction before input answers.

In part 1, Please choose one best answer from drop down list.
In part 2, Depending on your choice in question 5, same selection from question 5 will be appeared. Please input data in the blank section.
In part 3, Depending on your choice, 'Yes' or 'No', different questions will be appeared. Please do not disregard question 8.
In part 4, Please choose appropriate answer from drop down list. And, please do not forget to input the degree of relationships.

이 설문 조사지는 네개의 파트로 총 9문제로 이루어졌습니다. 소요시간은 약 15분 정도 입니다.
시작하시기 전에 꼭 읽어 주십시요.

Part 1에서는 한가지의 답만 골라 주십시요.
Part 2에서는 5번 문제의 선택에 따라서 같은 보기가 주어 집니다. 빈칸에 알맞은 데이터를 입력 해 주십시요.
Part 3에서는 예/ 아니오 의 선택에 따라서 다른 설문이 주어 집니다. 8번 문제를 지나치지 마십시요.
Part 4에서는 알맞은 항목을 선택하여 주십시요. 관계 정도를 입력하시는 것에 주의 바랍니다.

### Part 1. General Information about Your Company

Please select one appropriate answer from the drop down list.

1. How many years have you been working in construction industry?
(귀하는 얼마나 오래동안 건설업에 종사하셨습니까?)

2. What is the major specialty of your company?
(귀사의 특정 건설 분야는 무엇입니까?)

3. What is the average annual amount of construction work performed during past 5 years? (in US dollars)
(지난 5년동안 수행한 건설사업의 연평균 금액은 얼마입니까?)

4. How many employees work for your company?
(귀사의 총 직원수는 얼마나 됩니까?)

## Part 2. Identification of The Negative Factors for Construction Performance

5. Some negative factors related to data management are provided as below.
Please choose **ALL** negative factors that affected to your company's past construction project, and rate the degree of effects.
Note: Since this survey is mainly focused on the identification of DATs use, only internal factors related to data management are described.
(데이터 management 와 관련된 몇 가지의 부정적 요인들이 아래에 제시 되었습니다.
귀사의 지난 건설 프로젝트에서 부정적 요인으로 작용하였던 것을 모두 선택하여 주시고 영향을 미치는 정도를 평가해 주십시요.).
주의: 이 설문 조사는 DATs 사용을 위한 것이므로 이와 관련된 부정적 요인들만 다루어집니다.)

- ☐ Inappropriate Material Handling on Layout
- ☐ Late Material Handling from Layout to Specific Job site
- ☐ Late Material Delivery from Manufacturer
- ☐ Loss Productivity Due to the Waiting Time for Work Order
- ☐ Absence of Equipment on Specific Time
- ☐ Problems in Quality Management
- ☐ Workers' Injury or Accident
- ☐ Defective Works or Reworks
- ☐ Etc. (If you check this option, please specify the factors at below.)

Other Factor

6. According to the your selection in Question no 5, the selected factors are automatically reproduced as below.
Please input the approximate probability of occurrence for each factor in percentage value based on your past experiences. (e.g. 1 to 100)
(질문 5번의 선택에 따라서 아래에 같은 항목들이 자동으로 형성되었습니다.
각 요인들에 대하여 귀하의 지난 경험들을 바탕으로 대략적인 발생확률을 퍼센트 단위로 입력해 주십시요.) (e.g. 1 to 100)

This section is not a blank area.
Depending on your choice on Question 5, different question will be provided.

**Part 3. Identification of The DATs Implementation**

7. Does / Did your company use any automated Data Acquisition Techniques (DATs) on any construction project?
(귀사는 건설 사업에서 자동 DATs를 사용하셨거나 사용하고 계십니까?)

◯ Yes ◯ No

8.

This section is not a blank area.
Depending on your choice on Question 7, different question will be provided.

**Part 4. Identification of The Relationships between Factors.**

9. Based on your professional experiences, please specify the relationships between factors in detail, and rate the degree of relationships.
(귀하의 전문적인 경험을 바탕으로 각 요인들간의 관계를 자세하게 서술해 주시고 관계의 정도를 평가해 주십시요.)

A. [ ] is related to [ ] with [ ]

B. [ ] is related to [ ] with [ ]

C. [ ] is related to [ ] with [ ]

D. [ ] is related to [ ] with [ ]

E. [ ] is related to [ ] with [ ]

F. [ ] is related to [ ] with [ ]

G. [ ] is related to [ ] with [ ]

H. [ ] is related to [ ] with [ ]

I. [ ] is related to [ ] with [ ]

J. [ ] is related to [ ] with [ ]

If you need more space to input relationships between factors, please click 'ADD' button . ADD

If you need print out the survey form with your answer, please click 'Print Form' button. Print Form

Otherwise, please click 'Click to Submit' button.

Thank you for your valuable participation. Click to Submit

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Jintaek Ock was born in Seoul, Korea. He earned his B.E. degree in civil engineering from Yonsei University in 2002. After graduation from university, he worked in the environmental engineering field in the Seoul Metropolitan Government for 1 and half year. In 2004, he started his graduate studies majoring in civil engineering at the University of South Carolina, Columbia, and he earned master's degree in 2007. During his graduate studies he worked as research assistant for sustainable development research.

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