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A STUDY OF RFID APPLICATION FOR IMPROVING THE INSTALLATION PROCESS OF PRECAST CONCRETE PANELS IN A HOUSING PROJECT

Mr. Budi Hasiholan

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Infrastructure in Civil Engineering
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Thesis Title	A STUDY OF RFID APPLICATION FOR IMPROVING THE INSTALLATION PROCESS OF PRECAST CONCRETE PANELS IN A HOUSING PROJECT
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Field of Study	Infrastructure in Civil Engineering
Thesis Advisor	Vachara Peansupap, Ph.D.
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บูดิ ฮาซิโฮแลน: การศึกษาเทคโนโลยี RFID สำหรับการปรับปรุงกระบวนการติดตั้งชิ้นส่วนคอนกรีตสำเร็จรูปในโครงการก่อสร้างบ้าน. (A STUDY OF RFID APPLICATION FOR IMPROVING THE INSTALLATION PROCESS OF PRECAST CONCRETE PANELS IN A HOUSING PROJECT)
อ.ที่ปรึกษา: ดร. วัชระ เพียรสุภาพ. อ.ที่ปรึกษาร่วม: รศ.ดร. ธนิต ธงทอง, 169 หน้า.

การปรับปรุงกระบวนการก่อสร้างจำเป็นต้องอาศัยข้อมูลอยู่ 2 ประเภทกล่าวคือ ข้อมูลเพื่อการปฏิบัติงาน และข้อมูลตอบกลับที่ใช้ในการปรับปรุง ซึ่งในปัจจุบันกระบวนการปฏิบัติงานก่อสร้างประสบกับอุปสรรคในการได้มาซึ่งข้อมูล 2 ประเภทดังกล่าว เพื่อลดปัญหาดังกล่าวงานวิจัยจึงนำเสนอแนวคิดในการใช้ระบบ RFID ที่เป็นอุปกรณ์ระบุและรวบรวมข้อมูลอัตโนมัติที่ผนวกเข้ากับระบบฐานข้อมูล และทดสอบแนวคิดดังกล่าวโดยใช้กรณีศึกษากระบวนการติดตั้งแผ่นผนังสำเร็จรูปในโครงการก่อสร้างบ้าน

ในเบื้องต้นงานวิจัยนี้เริ่มต้นด้วยการทบทวนเอกสารและงานวิจัยที่เกี่ยวข้อง และการสังเกตการณ์ในภาคสนาม ผลที่ได้จากการศึกษาเบื้องต้นถูกนำมาใช้เป็นส่วนประกอบในการสร้างกรอบความคิดของแบบจำลองการประยุกต์ใช้ RFID ในกระบวนการติดตั้งแผ่นผนังสำเร็จรูป งานวิจัยนี้ได้ทดสอบแนวความคิดการใช้ RFID ด้วยการสำรวจลักษณะพิเศษของ RFID และการพัฒนาระบบต้นแบบเพื่อนำเอา RFID ไปใช้งาน

การสำรวจลักษณะพิเศษมีวัตถุประสงค์เพื่อที่จะได้ทราบลักษณะพื้นฐานของ RFID ที่สำคัญต่อการนำมาใช้สนับสนุนกรอบความคิดของแบบจำลองที่นำเสนอ ผลจากการศึกษาแสดงให้เห็นว่า ทิศทางและตำแหน่งของแถบป้าย ระยะทางและมุมของการยิงสัญญาณ และแถบป้าย RFID อื่นๆ ที่อยู่ใกล้เคียง มีผลต่อประสิทธิผลด้านการตอบสนองของ RFID โดยทิศทางในแนวดิ่งของแถบป้ายสามารถตอบสนองสัญญาณได้ดีกว่าทิศทางในแนวนอน นอกจากนี้คุณสมบัติด้านอัตราการอ่าน จำนวนสูงสุดของการตรวจจับแถบป้ายในครั้งเดียว และระยะช่องว่างระหว่างแถบป้ายมีแนวโน้มที่จะลดเมื่อระยะทางการอ่านเพิ่มขึ้น ในขณะที่พื้นการตอบสนองสัญญาณมีแนวโน้มที่จะน้อยลงเมื่อเครื่องอ่านหมุนห่างออกไปในทิศทางแนวนอนและแนวดิ่ง

การออกแบบและพัฒนาระบบ RFID เป็นต้นแบบที่มุ่งหวังให้ฝ่ายที่เกี่ยวข้องสามารถเก็บรวบรวมและเข้าถึงข้อมูลที่ต้องการได้ โดยระบบ RFID ประกอบด้วยโมดูลการเตรียมข้อมูล การเก็บข้อมูล และการแสดงผล โดยโมดูลการเตรียมข้อมูลและการเก็บข้อมูลทำหน้าที่เตรียมข้อมูลเกี่ยวกับรายละเอียดของแผ่นคอนกรีตสำเร็จรูปและบันทึกข้อมูลระยะเวลาของเหตุการณ์ต่าง ๆ ในกระบวนการติดตั้งแผ่นผนังสำเร็จรูปตามลำดับ ขณะที่โมดูลการแสดงผลทำหน้าที่แสดงข้อมูลที่ต้องการของแผ่นผนังสำเร็จรูป และข้อมูลระยะเวลาของเหตุการณ์ที่เกี่ยวข้องกับการติดตั้ง นอกจากนี้ข้อมูลของเหตุการณ์ติดตั้งสามารถเสนอในรูปแบบของตารางและมุมมองของรูปภาพเพื่อช่วยในการวิเคราะห์การติดตั้งแผ่นผนังสำเร็จรูปที่เกิดขึ้นในปัจจุบัน โดยระบบที่พัฒนาขึ้นสามารถให้ข้อมูลเพื่อการปฏิบัติงานและข้อมูลตอบกลับที่ใช้ในการปรับปรุงกระบวนการติดตั้งชิ้นส่วนสำเร็จรูป

ภาควิชา...วิศวกรรมโยธา	ลายมือชื่อนิสิต..
สาขาวิชา..วิศวกรรมโยธา........	ลายมือชื่ออาจารย์ที่ปรึกษา ....
ปีการศึกษา ....2549............	ลายมือชื่ออาจารย์ที่ปรึกษาร่วม ....

##4870593121: MAJOR INFRASTRUCTURE IN CIVIL ENGINEERING
KEYWORDS : PROCESS IMPROVEMENT/ INFORMATION/ RFID /FIELD-DATA COLLECTION/ PREFABRICATION

BUDI HASIHOLAN: A STUDY OF RFID APPLICATION FOR IMPROVING THE INSTALLATION PROCESS OF PRECAST CONCRETE PANELS IN A HOUSING PROJECT.
THESIS ADVISOR: VACHARA PEANSUPAP, Ph.D. THESIS CO-ADVISOR: ASSOC. PROF. TANIT TONGTHONG, Ph.D., 169 pp.

Two types of information, namely; related jobsite information along the process and feedback information have been found as essential elements for construction process improvement. In current practices, construction process has faced barriers in obtaining these two types of information. To overcome this problem, the new information system is proposed, namely; Radio Frequency Identification (RFID) system which consists of RFID as an automatic identification and data collection device integrated with database. Precast concrete installation process in housing projects has been selected to be a case study.

The research had been initiated by reviewing related literatures and conducting field observations. The results of these initial studies are utilized as a basis in constructing the conceptual model of RFID application in precast installation process. The conceptual model is then realized by exploring the RFID characteristics and developing the prototype of RFID system afterwards.

The exploration of RFID characteristics aims to reveal the basic characteristics of RFID that are essential to be recognized in supporting the proposed conceptual model. The general findings show that the tag orientations, tag positions, distance, interrogation angle, and the presence of other tags affect the RFID performance. The vertically oriented tag performs more superiorly than the horizontal one. The reading rate, the maximum amount of detected tags at once, and the minimum spacing distance between tags tend to decrease as the reading distance increases. The coverage area tends to be smaller when the reader rotates either horizontally or vertically.

The design and development of RFID system is a prototype. It aims to enable the involved parties to collect the required data and to access the required information. The RFID system involves pre-input, input, and output modules. The pre-input and input modules collect associated data to the details of concrete panel information, and the information of precast installation process respectively. The output module presents the required information of the precast concrete panel and the information of the installation events. The information of the installation events is presented in forms of table and graphical views to provide simple analysis of the current precast installation practice. The RFID system provides related jobsite information and feedback information which can be used to improve the installation process of the precast concrete panels.

Department ......Civil Engineering........................ Student's Signature ....
Field of Study . .Infrastructure in Civil Engineering. Advisor's Signature ....
Academic Year...2006 .... Co-advisor's Signature ....

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CHAPTER I

INTRODUCTION

1.1 Introduction

The implementation of prefabrication (precast) construction method has recently increased in many construction projects due to several reasons. They are an increase in the needs for all types of building particularly housing, limited available space for construction site, a rise in requirements in maintaining and/or achieving quality which can be originated from design requirements and adverse environmental conditions, and the need to provide affordable price of buildings which can be derived from the production of standardization for large in number but less vary in range components.

According to Gann (1996), prefabrication refers to the production of components under factory conditions, and their assembly on site. The use of prefabrication construction method aims to reduce costs, increase speed of construction processes, and improve quality (Gann, 1996). Comparing to cast-in-place construction method, prefabrication offers at least four distinct advantages which are shorter construction schedules, lower cost for mass production (large in number), fewer contracts for owners (in modular case), and improvement of construction or work quality (*Prefabricated modular buildings: lower cost, fewer headaches,* 1991). Although prefabrication method promises many benefits which are mentioned before, construction industry has not yet achieved all those. The limitations occur when prefabrication components have been transported to and assembled on construction site.

To overcome the above limitations, it is essential to explore how to improve the installation of prefabrication components on site. Based on prior research, several ideas are proposed to improve the productivity of prefabrication installation such as: designs, materials, quality control, and the effectiveness of process itself or process management. Gann (2000) studied the development of better designs, materials and components by observations in order to improve construction processes. His study focused on minimizing on-site work and improving the accuracy, speed, and quality of construction. Moreover, Mwamila and Karumuna (1999) pointed out that quality control had to be exercised towards productivity improvement in all activities such as designing, construction, manufacture/production of concrete constituent materials, and production of precast concrete elements/components. Finally, Picard (1998) and Koskela (1992) revealed the need to focus on efficiency of the construction process management to enhance productivity. Hellard (1993) argued for the need of process improvement to increase quality and productivity (cost and speed). He highlighted that improvement could be effectively achieved by controlling process, people, equipment, environment, and materials.

Although many studies reveal the benefits of improvement in design, material, quality control, this study will concentrate on process improvement. It can be stated that process improvement is one of several methods to achieve higher productivity since it can improve the information flow, minimize waste of labor hour, and reduce productivity loss. Harris and McCaffer (2001) suggested that process improvement can be carried out by three main approaches: systems, management, and work tasks.

Although these three approaches benefit to identify the issues and problems occur in construction processes, they require basic information for their analysis. First example is benchmarking as a part of the systems approach. It requires information of performance records from previous or other projects to compare their performance. Second, worker survey which is a part of management approach, needs information about current practice to identify work's constraints. Third, work measurement which is a part of work task approach, requires information about time record in executing tasks. All of this information has been perceived as feedback information. Mwamila and Karumuna (1999) stated that this type of information is useful for continuous process improvements in identifying the problem origin and determining corrective action. Under the process improvement concept, information can be found as basic and supplementary form which flows from one process to another to initiate the process itself.

1.2 Problem Statement

Information along the process can enhance the productivity by streamlining decision making process. At construction site, project managers or site engineers need information in a timely manner for supporting their decision. This information is commonly collected from reports which are transferred back to the jobsite. Reports are resulted from collected paperworks (at jobsite) which are then transferred to and processed at the main office. Problems in obtaining information have accumulated since those processes are time consuming; thereby create timeliness and accuracy problems. Thus, this leads to the difficulty of obtaining accurate and timely jobsite information and record keeping. As a result, the obtaining of information can be seen as an essential part in the process improvement. It can be perceived as an activity to gain feedback for supporting in making decision during the process. However, failures to provide important information will be the basis of delay, dispute, cost overrun, etc.

Time consuming tasks in capturing and storing information about the processes, become barriers of process improvements. For example, in acquiring time records of the installation prefabrication components, extra workers are required to record the process and complete specific forms manually. In addition, manually-recorded information is collected as data is required to re-entry into electronic formats for further analysis.

Based on the above constraints, information technology (IT) can be used to support process management by reducing tedious, time consuming, and inaccurate project paper works that characterize the construction process (Adrian, 2004). In addition, IT encourages processes by providing current information in a timely manner, enhancing communication between parties involved in the project, and enabling new approaches in doing processes.

Thus, many studies have recently been conducted in the construction sector in order to investigate the relationships between IT and processes. Aouad et al.(1999) has classified ITs into six main headings which are comprised of simulation (e.g. project simulation), integration (e.g. integrated databases), communication (e.g. EDI, Internet), visualization (e.g. VR, 3D), and IT support (e.g. CAD, project planning, cost control). These ITs can be used to support process management in construction processes.

This research attempts to bring new perspective that field construction does not only require ITs for management but also needs to integrate with some electronic input device. RFID (Radio Frequency Identification) as one of those technologies and several ITs are examined in this research. They are expected to support the prefabrication installation process. As a result, the enhancement in the following ways is investigated:

- planning, monitoring, and record keeping information (arrival time of precast components, installation time, waiting time),
- obtaining quality control information (number of defects), and
- providing knowledge about precast installation (labor skill, installation sequences problem).

Consequently, the study yields findings that lead to timely information and provide feedback information for process improvement which impacts decision making at the management level.

1.3 Objective of the Research

The main objective of this research is to apply RFID for construction process improvement by using a case study of prefabrication installation in housing projects. It aims to utilize RFID in obtaining feedback information and providing related jobsite information that can be used for process improvement.

1.4 Scope of the Research

Generally, prefabrication construction method is used in housing, multi storey, and industrial buildings where the building's components are large in volume and less varied in range to obtain the economy of large scale production. Since this research is considered as an experimental stage of applying ITs to improve the installation process of prefabrication components, thus a housing project is chosen to be a case study. Despite applying ITs in recording information of prefabrication installation, process improvement which can be done by three approaches namely: systems, management, and work tasks are carried out into two approaches which are management and work tasks. Systems approach focuses on the organizational level whereas this research mainly focuses on operation (and process) and task levels, thus systems approach is not within the scope of this research.

1.5 Methodology of the Research

This research is conducted through the following steps:

- Review related literature in prefabrication, productivity improvement, process improvement, and ITs application in construction industry. Literature review also covers current practice of prefabrication installation process.
- Explore the RFID Characteristics and find the best usage of RFID application in precast installation process.

1.6 Contributions of the Research

This research generates the following contributions:

- The understanding about the problems of prefabrication installation process.
- New system in installing prefabrication with implementing RFID and ITs.
- Improved process after implementing IT applications and using a new system in installing prefabrication.
- Further possibility of RFID and ITs implementation into prefabrication construction method in terms of automation, integrated database, etc. which hopefully results productivity improvement.

CHAPTER II

LITERATURE REVIEW

2.1 Prefabrication Overview

The following section introduces prefabrication as an industrialized construction technique originated from manufacture of construction materials and components (Kjeldsen, 1976). In order to provide the understanding of prefabrication, it is essential to give an overview of several prefabrication definitions from three main perspectives which are industrialization, manufacturing, and components.

Those three main perspectives which are strongly related to each other, help to create a better understanding of prefabrication. For prefabrication from industrialization perspective, Koncz (1968) has seen it as an industrialized construction method. It aims to overcome the construction industry and economic constraints such as high demand of housing and requirements to the quality consistency. Mass production components are produced and assembled on site with the assistance of lifting and handling appliances. Secondly, manufacturing perspective has seen prefabrication as a manufacturing and pre-assembly process, generally taking place at a specialized facility, i.e., a factory, in which various materials are joined to form a component part of the final installation (Winch, 2003; Tatum, Venegas, and Williams, 1986). Lin (2001) added that there is a need in transporting to the site for final positioning. Thirdly, from the components perspective, prefabrication is seen as a building technique. A technique that is where concrete components are produced either in a factory or at a fixed location on site, and then completed elements are erected and assembled in situ to form complete building structures. The production of components can be standardized to reap economies of large scale production. Thus standardized moulds can be utilized many times without any irreversible modifications (Warszawaski and Cornel, 1984; Msambichaka, 1990).

2.1.1 Industrialization behind the use of prefabrication

According to Koncz (1968), prefabrication is the translation from craft to machine production, which generally entails prefabrication in a centralized factory while industrialization can be denoted as a machine production. Unlike in the machine production, in the craft construction, the bulk of the works done on site which are triggering labor and processes are all subjected to the vagaries of the weather (Peng and Chuan, 2001). The one-off nature of construction and its hostile environment make the achievement of a substantial level of mechanization difficult, let alone automation. Moreover, Peng and Chuan (2001) observed if those conditions remained, the labor –intensive nature of construction would continue to be so, and its productivity rates would remain low.

According to Gann (2000), as observed from the past that the construction sector followed paths of development from the mid nineteenth century to the early 1970's which were craft and industrialization production. The observation yielded the following table:

Table 2.1 Two paths of development, 1850s to 1960s (modified from Gann (2000))

	Craft	Industrialized
Process	Handicraft	Development of in situ assembly
Markets	Small-scale traditional markets : residential, repair and maintenance	Large-scale projects, new markets: construction of infrastructures, mass-housing, slum clearance, factories, offices, schools, and hospitals
Product	Bespoke (custom made), made from basic materials	Standardized, made from factory-produced components
Type of firm	Small, using locally available resources	Large, national or international; suppliers sometimes monopolizing regions or part of oligopoly operating cartels using chains of smaller subcontractors
Skills	Craft trades demarcated by skills associated with the use of particular materials	Specialized, narrow technical skills, fragmentation of old craft skills, growth of new skills associated with new materials and techniques
Learning	Cumulative	Application of scientific and engineering knowledge
Innovation	Unstructured, informal	Structured, formal R & D
Technological change	Incremental changes, adaptation of "tried and tested" techniques based on the use of traditional materials	Major changes such as prefabrication and the development and use of new materials, construction plant and equipment
Organizational change	Minor adaptations to traditional craft forms	Adoption and adaptation of methods used in manufacturing

According to the path of construction development between craft and industrialization as described above, it is inferred that industrialization becomes the key for construction regarding to unbalance conditions which can be considered as constraints that commonly occur in construction industry at many countries. Failure to answer those constraints can lead to serious problems for the construction industry. Those conditions are as follows (Kjeldsen, 1976):

1. the disproportion between the demand, not only for housing but for all types of buildings, and the capacity of the building sector.
2. the increasing requirements of quality.
3. the increasing production price of the buildings.

Koncz (1968) stated that the industrialization of construction had brought many impact to the construction industry itself, e.g., the design of the building had to be complementary to the procedures of manufacturing the components and of assembling them. Human labor was replaced by investments, capital outlay, just as in any other industrial undertaking. The higher the degree of mechanization and more efficient the manufacturing technique, the larger would be the capital expenditure involved.

Finally, the adoption of the industrialization into construction industry have yielded the following results (Kjeldsen, 1976):

1. an increase in capacity, whereby the growing demand for all types of building could be satisfied.
2. avoidance of the problems arising from the inadequacy of traditional building methods.
3. higher productivity with a lower manpower consumption, better utilization of unskilled labor and improved working conditions.
4. shorter construction time, which mean not only a reduction of the time used at the building site, with consequent savings on interest payments, but also a more rapid turnover of invested capital.
5. improved quality achieved by planned product development, efficient quality control, uniform products and independence of climatic conditions at the worksite.

2.1.2 The manufacturing of prefabrication

Gann (2000) stated that the industrialized production of construction materials and components, together with the new construction techniques, were stimulated by the adoption of engineering and production philosophies from other rapidly expanding industries. A study of innovations in the construction sector of 15 countries (including Japan, the US, and the UK) showed that in general “ideas from advanced manufacturing and information technology will migrate more rapidly to the construction sector and the novel approaches for site assembly will be developed” (Manseau & Seadan, 2001). Many studies (Crowley, 1998; Veeramani, Tserng, & Russel, 1998; Gann, 2001) have turned to the manufacturing industries identifying technology transfer potential for improving construction productivity and quality.

Peng and Chuan (2001) revealed that the manufacturing sector had always been a leading sector in so far as productivity was concerned. It was given that the sheltered and controlled environment as well as the extensive use of mechanization and automation in the manufacturing setting. In addition, the use of standardization and pre-assembly in the machine age along with the repetitive production of standardized products gave rise to operational efficiency as well as economies of large-scale production which had been demonstrated by manufacturing industries by showing that as the volume of production grew, cost per unit could be reduced quicker than production cost increased (Peng & Chuan, 2001; Gann, 2000).

According to Gann (2000), manufacturing processes which involved the concentration of materials, fixed capital, and labor in one or more places, resulted in the successfulness in demonstrating improvements in efficiency over scattered craft production found in many traditional industries, including construction. Gann (2000) found that there were three main advantages provided by manufacturing over the craft:

a. economies of scale, when the cost per unit produced dropped more quickly than production costs rose as the volume of materials processed increased;
b. technical possibilities to develop and deploy capital equipment;
c. the opportunity for tighter managerial control.

Improvement in manufacturing resulted in the ability to exploit technical possibilities and deploy new capital equipment aimed at improving productivity and quality in the production of building components which would require radical changes in overall design and construction processes (Gann, 2000). Prefabrication as manufacturing and pre-assembly process has enjoyed the advantages mentioned above and been affected in their way of designing and construction processes. For example, architects and engineers will need to understand the implications of their designs for manufacture, assembly and systems integration, particularly with respect to the interconnection of parts.

2.1.3 Prefabrication components

Gann (2000) noted that some buildings and structures, such as office buildings, were constructed from a large range of parts whereas others were designed from a large volume but small range of parts, for example, many civil engineering structures. Koncz (1968) asserted that prefabricated construction first made its entry in industrial building as a more promising field for prefabrication due to the large structures and the numerous repetitive components, the relatively simple shapes of the buildings in section and plan, and less exacting requirements as to finish. But later on, Poon et al. (2003) revealed that prefabricated building components were more widely used in public housing projects since most of developer felt that the use of prefabricated construction methods would bring advantages in many forms for them. Conclusively, a large volume in production but small range of parts is the main characteristics of product types, together with the size of market, have a strong bearing on the possibilities of using standardized pre-assembled components. Gann (2000) described that prefabrication construction method would result in a significant reduction in waste development, the increasing in speed of construction on-site, reduced labor demand, and the quality of the finished product.

According to Ballard et al. (2003), one opportunity for improvement in the construction process is to standardize design, so that products can be made to order rather than engineered to order. Most precast concrete components (walls, beams, columns, etc) are engineered-to-order products. Engineered-to-order products include elevators, some electrical and mechanical equipment, curtain wall, HVAC duct, structural steel, and many more.

Prefabricated structural components made of concrete are referred to as "precast units" (precast members" or "precast elements" are terms alternatively used), signifying that they are cast in advance and given time to harden and acquire strength before being taken to the actual construction site for assembly (Koncz, 1968). Construction methods which make use of prefabricated components are collectively referred to as "prefabricated construction".

Peng and Chuan (2001) pointed out that prefabrication arose with the hope of reaping the benefits of factory-styled operations where work processes were brought off-site and components were produced under the controlled conditions of a sheltered environment whereas the construction site then became an assembly station where the factory-fabricated components were brought on site to be assembled and installed. According to Clarke (2003), there were numerous reasons why the controlled conditions of factory made prefabrication provided a strong sustainability profile:

- High quality
- Accumulated experience vested in one place
- Consistency of strength, appearance, and color
- Dimensional accuracy
- Minimal waste
- Integrated design and manufacturing team in one place

The objective of factory production is to turn out large series of precast units but the size and weight of the individual units are limited by the possibilities of handling and transport (Koncz, 1968). They may be manufactured in stationary moulds, which in case of pre-tensioned prestressed concrete components are arranged on preanchored by being embedded in, and thus being directly bonded to, the concrete. Alternatively, the moulds and the units may be moved along during the manufacturing operations; in this way a kind of production line process is obtained.

After assembled the precast should require no or only very little subsequent treatment for finishing operations. This means the prefabricated components should already consist of the various finishes, surfacing, doors, and windows (Koncz, 1968). He asserted that these items of finish (in its widest sense) are great importance more particularly in housing construction. This will be readily understood when it is considered that the walls represent only about on-fifth of the total cost of a house.

2.1.4 The advantages and disadvantages of prefabrication

In deciding to utilize prefabrication construction method, it is essential to know the possible advantages can be obtained and disadvantages that might have to be bore. Thus in this section, advantages and disadvantages of prefabrication will be discussed. According to Poon et al. (2003), relative advantages of prefabrication construction method under several conditions such as general market conditions, general project conditions, and architectural features are listed in the table below:

Table 2.2 Relative advantages of prefabrication construction method under various conditions (Warszawski, 1999)

	Advantage of (Construction Method):	
Building Conditions	Prefabrication	Conventional
General market conditions		
High volume demand for buildings	✔	
High construction wages	✔	
Lack of skilled workers	✔	
General project condition		
Large and repetitive project	✔	
High quality of work required	✔	
Architectural features of the project		
High modularity of dimensions	✔	
Special non-regular shape of the building		✔
Special performance needs of the building		✔
Special aesthetic requirements from components		✔

The advantages offered by industrialized methods of building construction have already been enumerated frequently. For this reason only some of the most important advantages will be mentioned here namely:

1. Quality control: Better quality of the products is obtained as a result of manufacture under factory conditions with secured quality control, the use of machines, and the better working environment provided by factory. The use of machines enable several benefits such as higher tolerances, more accurate measurements, with less maintenance and material waste, and greater consistency of finished products (Koncz, 1968).

2. Production control: Involving programmed production, a timely delivery and/or erection can diminish the need for large stock inventory left in the factory or on the site. Construction is faster on the site where a more efficient order of building sequences can be maintained (Koncz, 1968).
3. Inventory control: The tighter inventory controls possible in a factory setting, over small-piece building materials and components-piping, ducts, fans, windows, bricks, and tools-virtually eliminate the high rates of theft and vandalism on the site (Koncz, 1968).
4. Labor control: Less manpower is needed, since the precast units are manufactured in a factory or, at any rate, under factory conditions on the building site. Instead of skilled labor, unskilled workmen can be used, who do not have to travel around site to site. This leads to lower on-site labor cost along with that faster construction leads to reduced general contractor overhead, lower interest paid on construction loan, earlier occupancy and quicker investment return (Koncz, 1968).
5. Climate control: Construction can proceed almost independently of weather conditions, since the units can be manufactured in covered buildings which can be heated and released from the “building season” limitations imposed by their climate conditions, and erection of the units can also carried out in winter (Koncz, 1968).
6. Problem control: The detailed appraisal of constructional problems before work begins results in fewer delays in construction after commencement on the site (Koncz, 1968).
7. Shorter total project time: Precast concrete construction reduces total project time since units of components are cast and stockpiled while other phases of the project are carried out, thereby reducing the total required time. Accelerated curing methods further speed up the casting of precast components. Continuous uninterrupted erection of components makes the rapid formation of structural frame possible (Lin, 2001).
8. Materials requirements are reduced: Precast concrete technology will significantly reduce the need for formwork carpentry as re-usable metal forms can be specially made for use in the prefabrication yard so the use of formwork, reinforcement and concrete can be better controlled and wastage reduced (Peng and Chuan, 2001). Prefabrication construction method also reduced the need of scaffolding since almost all components are formed in the factory and do not need temporary support unless for assembly phases. The reducing in temporary support needs can enable the use of favorable light-weight structural sections which in turn need less concrete and steel. As the result, the weight of the whole building can be reduced.
9. Expansion enabled: Precast concrete can be designed to facilitate future horizontal or vertical expansion. Thus with the design of precast concrete buildings on modular system, necessary additions can be made with low

removal costs. They may also be erected without false-work, maintaining uninterrupted traffic movement. Precast elements are quickly erected in buildings providing an instant platform for other trades (Lin, 2001).

Nevertheless, there are certain drawbacks of prefabrication construction method. Those disadvantaged are summarized as follows:

1. The joints between members pose the greatest problem. Adequate design and detailing are required for a joint to be easily formed on-site while at the same time providing the required strength. As it is essential for precast components to be manufactured well in advance of the other building activities, flexibility for subsequent changes may be little. It is also essential for precast concrete components to be designed to function as part of a total structure but also to withstand stress conditions during handling, transport, and erection (Lin, 2001).
2. In order to obtain the greatest economy in precast concrete construction, a high degree of repetition is required. It is less suitable for structures with irregular or isolated features. In the case where precast units are gigantic, large capacity cranes and handling equipment are needed (Lin, 2001).
3. There is the problem of transporting the prefabrication components from the factory to the site which is more difficult than the transport of materials and erecting and interconnecting them to form the final structure. These operations associated with prefabrication entail additional cost and technical problems (Koncz, 1968).
4. The components and their details can be also standardized to reap economies of large-scale production. A major concern over standardization is the lack of variety. For the industry to embrace precast concrete technology, costs and variety are major considerations. To meet the needs for greater variety, prefabrication should move towards “lean production” and away from the usual mass production. This refers to the production of smaller but economically viable volumes of standardized components, specially tailored for a project (Peng and Chuan, 2001).

To sum up, prefabrication technology therefore brings with it host of benefits: improved quality with better quality controls, reduction in wastage, less labor intensive operations, faster production of building components and economies of large-scale production (Low and Chan, 1996). All this eventually results in reduction price and better working conditions for the building operatives. According to Koncz (1968), because of the substantial shortening of the construction time, further savings can be affected (interest on capital, earlier commencement of production, etc.). These are not easy to estimate numerically and will not come instantly since at the very beginning it will come with an increase in costs. This increase in costs can be minimized or offset over the years as the industry becomes more familiar with the technology, thus reducing the risk factor, and the leading to greater standardization and repetitions (Peng and Chuan, 2001). It is essential to know that lower economic returns will occur when the projects scale is small, and lower flexibility for design variations. The feasibility of using prefabricated construction methods must take into account the economics, site situations, architectural features, and the anticipated uses after building completion (Poon, Yu et al., 2003). In general, advantages occur when the project scale is large and of a repetitive nature, or when high quality of work is required (Poon, Yu et al., 2003). Moreover, he concluded that it is not the best choice if the building form is of an irregular shape, or if the layout changes during and after construction are anticipated.

Despite of all the advantages mentioned above, prefabrication construction method has not yet been liberated from problems related to designs, materials, quality, and the effectiveness of process itself (process management). These problems have impeded the benefits and productivity of prefabrication. Thus, these related problems are needed to be solved to achieve a higher productivity and all promised benefits.

Many studies have been conducted into different approaches for solving these impeding problems. Those approaches vary from the development of better designs, materials, and components to the exercise of quality control in all precast construction activities. This research focuses on the process of prefabrication installation and improvement of the process as a quest to obtain a higher productivity.

2.2 Process Improvement

Process improvement is a method of productivity improvement. A higher productivity does not only concern about how to boost the output or diminish the input number. Beyond that, higher productivity can be achieved by looking into the process, evaluating the current process to gain feedback and conducting a continuous process improvement. Although productivity is fundamentally an output to input relationship, the productivity can be improved not only by looking at the numerator and denominator but also by investigating the throughput process itself. This is endorsed by Hellard (1993) which noted the need to focus on the process for quality and productivity improvement (cost and speed) stems from the fact that, improvement would come only by good control of the process, people, equipment, environment, and materials. Thus, process becomes the key in achieving higher productivity.

Generally, process is simply defined as a series of connected task that produce some outcomes or it can be seen as a task to receive some inputs (Mwamila and Karumuna, 1999). Similarly in construction industry (as seen in **Figure 2.1**), process generates construction products in the form of buildings, roads, bridges, etc. To produce those, it requires resources as input, namely: manpower, materials, machine (equipment), and money (capital). Those resources are formally known as 4Ms of construction (Halpin and Woodhead, 1998). Each of the four resources represents a number of factors which have to be taken into account. On the other hand, output in construction process is constrained with three parameters which are time, cost, and quality. In the middle, construction process will transform resources as input into construction products as output, comprises at least two components inside, namely: process management and construction method.

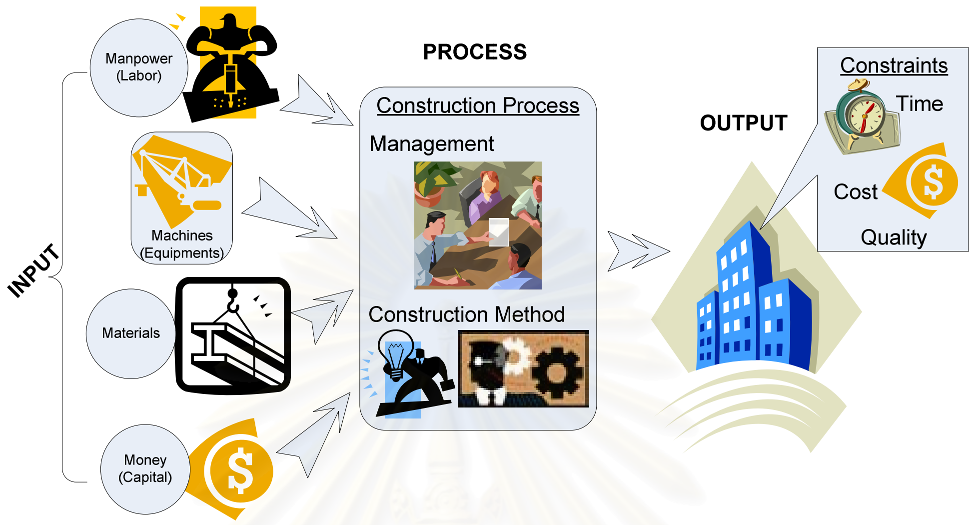


Figure 2.1 General components of construction process

Based on the above definition, construction process is referred to the transformation of resources into construction products. For instance, manpower (labor), by using machines (equipment) or its own effort, process the materials and meanwhile the money (capital) funds those i.e., for disbursing the manpower's effort, buying machines or pays the rental bills, and pays the suppliers for the materials. Construction method plays an important role in determining how to build the construction and then followed by the determination of equipment will be used. Meanwhile management directs all resources to achieve the objectives (i.e., expected construction products) but at the same time have to satisfy all constraints (i.e., time, cost and quality) by planning, organizing, executing, monitoring and controlling.

Then, when the output is not anticipated one (in terms of cost, time, and quality), the feed back information will facilitate identification of the problem origin and the determination of the corrective action (Mwamila and Karumuna, 1999). This is possible to do by tracing back and identifying the problem's sources which can be done by implementing management function inside the process. This is supported by Maloney (1990) who analyzed process management as a new possibility for increasing productivity and concluded that process management focused on the efficiency of the overall work process by analyzing work flow. Furthermore, he pointed out that process management complemented production management by ensuring the efficient, productive use of project resources, as in the well-known expression for efficiency.

Commonly, management plays a control role inside process, Thomas et al.(1990) found that productivity could be best optimized by modifying those aspects of working environment over which management had controlled. Many ways have been used in process improvement; one of those is work study which will be discussed later. Thomas et al.(1990) noted that many work study practices failed to differentiate between controllable and uncontrollable factors. Handa et al. (1990) insisted that controlling the factors which were affecting productivity offer far greater improving productivity than modifying or changing the work method. Unlike the typical manufacturing situation, changing the method usually yields minor, short term gains (Thomas, Maloney et al., 1990).

Conducive climate which supports construction processes is highly demanded where all resources as inputs together with management as a component in process are combined and directed towards augmenting productivity and quality (Harris and McCaffer, 2001). Moreover, they explained the aim of these which was for achieving a certain level as targeted of output with less input therefore a partial measure of productivity (the ratio of output divided by input) focusing on input's components would be field managers' prime concern. As mentioned above, productivity is not as simple as output and input relationship but more profound its process. How can the process be improved?

Process improvement is one of many attractive research topics to be conducted in construction industry. Many methods of process improvement are adopted from manufacturing regardless of construction operation uniqueness. In this research, there are three approaches of process improvement, namely: systems, management, and work task (work study). Beside those approaches, improvement of the process can also be obtained by providing all resources that are required to initiate the process including work information. Related jobsite information along the process which is provided in a timely manner, accurate, and real time enhances process decision making. The three approaches of process improvement will be discussed briefly in the following section.

2.2.1 Methods of Improving Construction Process

A framework (as described in the following figure) has been offered to do a continuous improvement in performing construction process by Harris and McCaffer (2001).

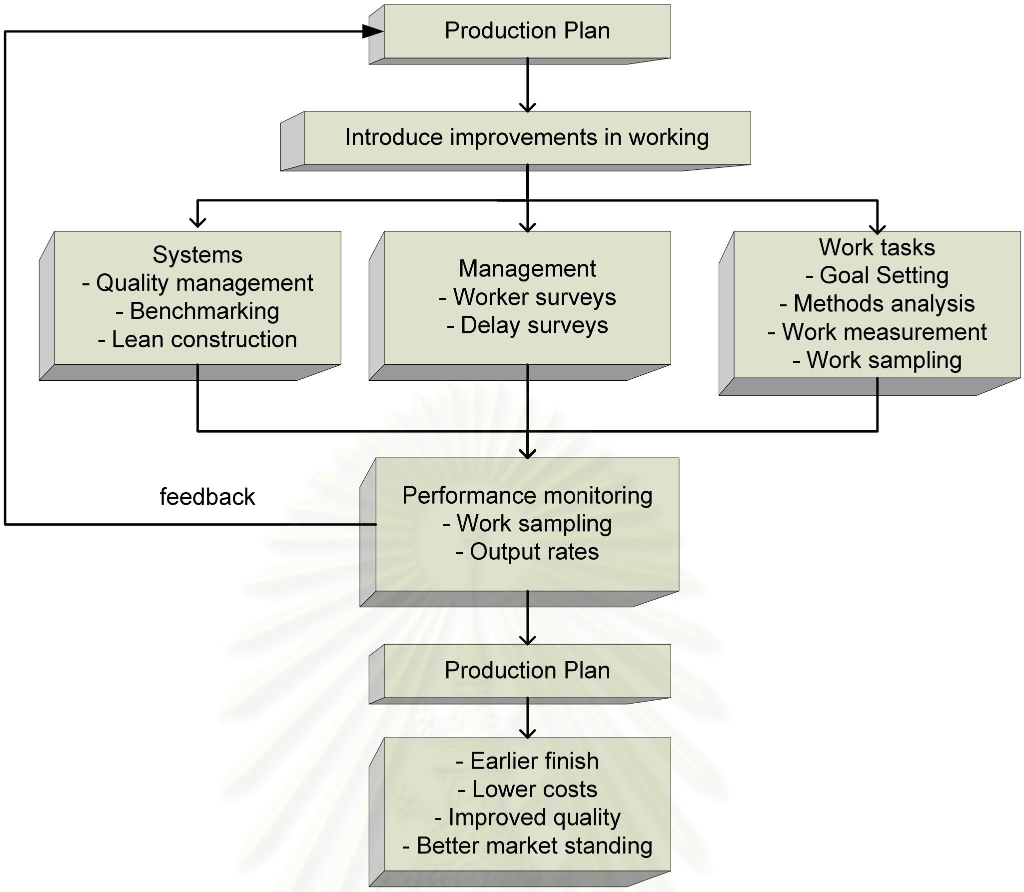


Figure 2.2 Proces for continuous improvements in construction processes (Harris and McCaffer 2001)

This framework comprises of three approaches namely systems, management, and work task (work study). According to Harris and McCaffer (2001), in achieving expected result, as illustrated in **Figure 2.2**, the first and fundamental step is by establishing clear systems to achieve continuous improvement. Meanwhile, management approach has to ensure a well managed and supervised working condition and environment. Along with the above two approaches, work task approach conceives optimal methods of working for construction activities and work task. Finally those approaches are wrapped up with monitoring and controlling output. By following this framework, achievement of an earlier finish, a lower cost, an improved quality, and an increasing in the competitiveness of company in the market will be gained.

2.2.1.1 <u>The Adoption of Manufacturing Managerial Concepts to Construction</u>

How adaptable the manufacturing concepts can be applied into construction industry? Mohamed (1996) pointed out that total quality management, lean production, benchmarking, just in time, computer integration, automation, and many more were examples of manufacturing concepts which had been imported from manufacturing to be implemented in construction, had always been investigated and verified of their applicability to construction and some of these concepts were successfully adopted in construction which depended on the effectiveness in accommodating the differences between manufacturing and construction operating environments. Based on a comparison concerning the basic processes and functions of manufacturing and construction industries, Sanvido and Medeiros (1990) reported several distinctions between manufacturing and construction even though both produced engineered products that provided a service to users and might include processing of raw materials and assembly of many diverse pre-manufactured components in the final product.

Manufacturing differs from construction in terms of product characteristics i.e., complexity and production volume; and their environment. For example, manufactured products are made in a factory and transported to their final use location, while construction products are built in place. Therefore the manufacturing environment is well controlled comparing with construction. This condition also means that process equipment, material paths, and physical work area stay rather steady. In contrast construction work deals with changes since component product is installed in place so each time the working area changes, process equipment and material handling equipment have to be adjusted with the new environment. Furthermore, construction products are commonly more complex, heavier assemblies built to lower tolerances than manufactured products and typically produced in smaller volume but vary in types so difficult to implement the automated assembly line but this is an exception for prefabrication construction method.

Prefabrication construction method is an example of industrialized production in construction industry which is adapted from manufacturing industry. In adapting and implementing manufacturing production and managerial concepts, it is essential to realize the existence of product characteristics and working environment which affect the manufacturing's concepts applicability in construction industry.

2.2.1.2 Management Levels of Construction

As mentioned before, there are three approaches in this research to improve construction process, i.e., systems, management, and work study (work task). Each of these three distinct approaches is implemented into different levels of management. Systems are considered to be implemented into organizational level meanwhile management and work study are implemented into activity together with operations (and process) and task level respectively. These implementations based on the scope of each approaches, are carried out and generated effects differently.

Halpin and Woodhead (1998) explained that organizational considerations led to a number of hierarchical levels that could be identified in construction which derived from a project format. In addition, decision making at levels above the project relates to company management considerations (e.g., selection of production methods) as well as the application of resources to the various construction production processes and work tasks selected to realize the constructed facility (Halpin and Woodhead, 1998).

Furthermore, they described the hierarchical level in project as shown in the figure below.

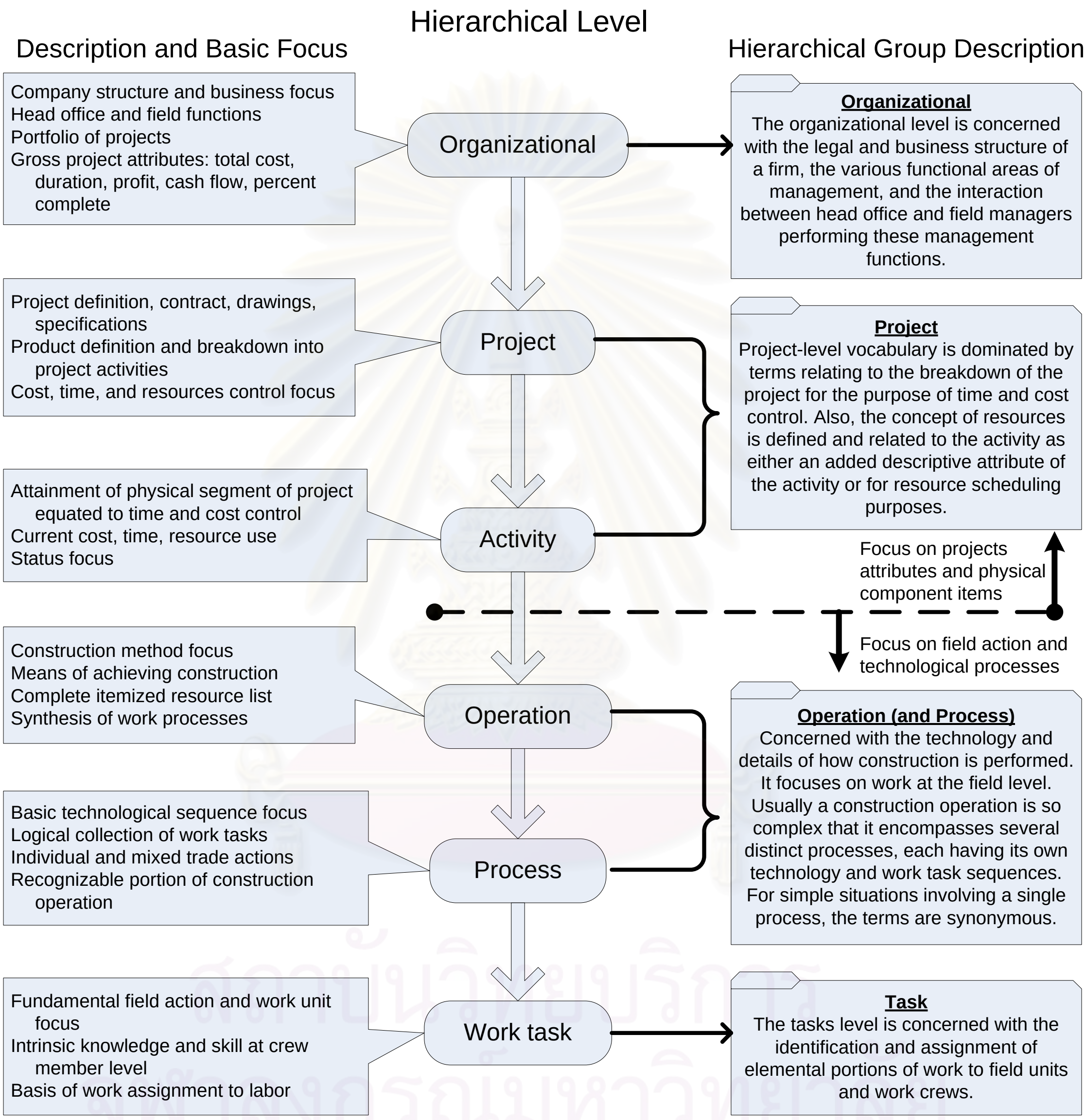


Figure 2.3 Hierarchical levels and group in construction management (adapted from Halpin and Woodhead, 1998)

The relative hierarchical breakout and description of these levels in construction management are shown in **Figure 2.3**. It is clear that the organizational, project, and activity levels have a basic project and top management focus. While the operation, process, and work task levels have a basic work focus.

Based on the previous figure, it is clearly noticed that the organizational level is a potential area in implementing systems approach whereas work study (work task) approach is best applied in task level meanwhile management approach is implemented in project, activity, and operations (and process) as a bridge which connects and delivers the upper management's policy so it can be clearly accepted and implemented in field task action. Since this research is focused on improving the process of prefabrication installation which affects operation (and process) and task levels then only two approaches are conducted and discussed. They are management and work task approaches.

2.2.2 Process Improvement by Management Approach

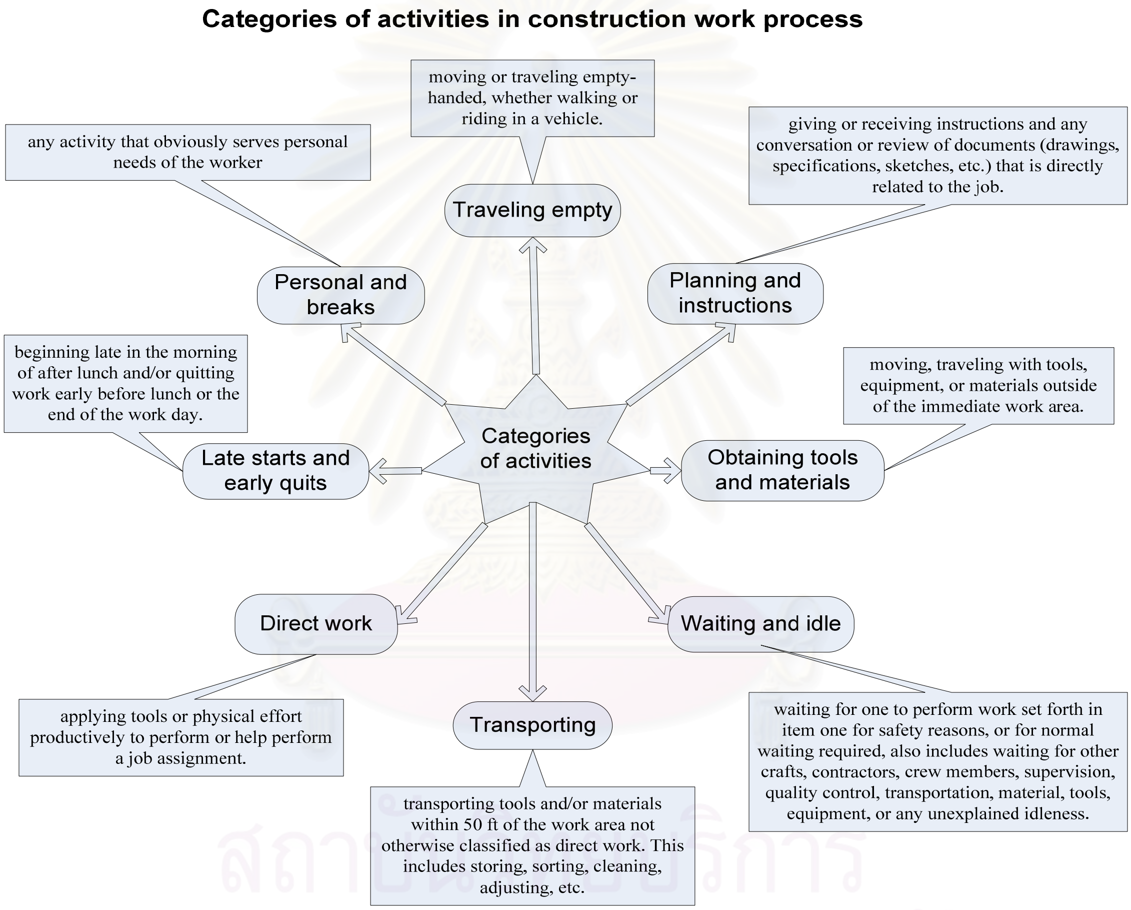
Management involved in the process to transform resources into desired output by managing the work which can be done in the form of planning, scheduling, controlling, and providing the required resources to initiate the process so the workers can perform their duty effectively and fully utilize their capabilities of being imposed of constraints by management's failure (Maloney, 1990). In addition, he described that failures to provide the workers with required resources such as equipment, materials, tools, and work information will reduce worker performance since they have to seek and wait until the required resources are provided to commence the work.

Management approach aims to form a favorable work-climate for workers. This can be done by identifying and removing obstacles to efficiency and effectiveness in work process. Furthermore, based on the perspective of Picard and Jr. (1996), once obstacles identified and quantified, they can be reduced or eliminated through improvements in work process, e.g., to increase the productive use of the available work hours, streamline the workflow, remove craft obstacles and delays, and reduce errors and confusion. To reach a higher productive activity, management does several actions as follows:

1. Work has to be done in sequence; failure to have prerequisite work completed will reduces worker performance because time is lost while the constrained crew is relocated to another task.
2. Work must be scheduled to minimize congestion because crew or worker interferences reduce worker performance.
3. Crew must be sized appropriately for the task to be performed. If crews are too large, significant periods or idle time will occur or can lead to. Crews that are too small require crew members to perform additional duties that constraint output.

Production rate of a construction operation is constrained by many factors which are influenced by the management practices. Thomas and Mathews (1986) noted common examples including weather conditions, work experience/ skill or workers, interference from other crews (overcrowding), construction method used, and material delivery/ storage/ handling procedures. In practice, management does work sequence, work schedule, crew sizing, and weather effects' mitigation to eliminate constraints on worker performance. Maloney (1990) explained that ineffective management served to increase unit rates above what they would have been without the constraints.

The data typically used to identify the constraints are obtained through two different but related types of studies: worker surveys and delay surveys. But before identifying the constraints, we should know activities in construction work process which are described by Maloney (1990) and divided into eight categories as shown in the following figure:



Maloney (1990) noted that the direct work category represents productive activity

Figure 2.4 Categories of activities in construction work process (adapted from Maloney (1990))

2.2.2.1 <u>Worker Surveys</u>

Based on research findings by Broomfield et al. (1985), the cause of lost production times are usually interconnected and typically arise through unsatisfactory execution of managerial and supervisory functions surrounding short term planning, daily, and weekly scheduling, materials standardization and control, information flow, constructability of design, subcontractor and suppliers' performance, workforce goals and competency rather than specifically in the methods of working.

Structured questionnaire surveys conducted by Zakeri et al.(1996) presented detailed information obtained directly from the workforce. Their findings show several problems impeding construction production that identified. These problems will need to root out the causes and devise remedies. The surveys' results are excessive weather delays, equipment breakdowns, drawings and/or specification changes, variations orders, inadequate tools or equipment, inspection delays, absenteeism, poor work planning, work interference, poor communication. The surveys also address that the lack of materials and repeat work are problems impeding the production. Lack of materials occurs due to waste, transport difficulties, improper handling on site, misuse of the specification, lack of a proper work plan, and inferior materials or excessive paperwork. Meanwhile rework occurs due to poor finishes, negligence, congestion, overcomplicated drawings and/or specifications, poor job opportunity, harsh/fatiguing working conditions, poor work facilities and lack of materials.

2.2.2.2 Supervisor Delay Surveys

As implied from the name, the surveys put a supervisor as an evaluator in acquiring site specific data of production problems. Harris and McCaffer (2001) illustrated that supervisor delay surveys (SDS) could help to identify time losses of the crew at the end of the working day and to reveal areas of inefficiency resulting from factors other than those due to the performance of the workforce. Moreover, they revealed that SDS technique potentially provides a cost-effective tool particularly useful for evaluating managerial related problems. SDS technique has the following features:

1. It provides a link between management and supervisors facilitating discussion of problems and means of solution.
2. Delays to particular groups of worker are immediately highlighted.
3. Information is provided on particular aspects, such as materials, sub-contract interference, drawing information, plant availability, etc.
4. The whole project can be readily monitored.
5. The survey is inexpensive to carry out, can be done regularly and by untrained personnel.
6. The information is current.

2.2.3 Process Improvement Using Work Study Approach

A systematic study of work systems for the purposes of finding and standardizing the least-cost method, determining standard times, and testing in training in the preferred method called work study which is sometimes called a time and motion study (Barnes, 1980). British Standard Glossary defined work study as a measurement service based on those techniques. The work study can be categorized into two approaches called method study and work measurement (as seen in the figure below).

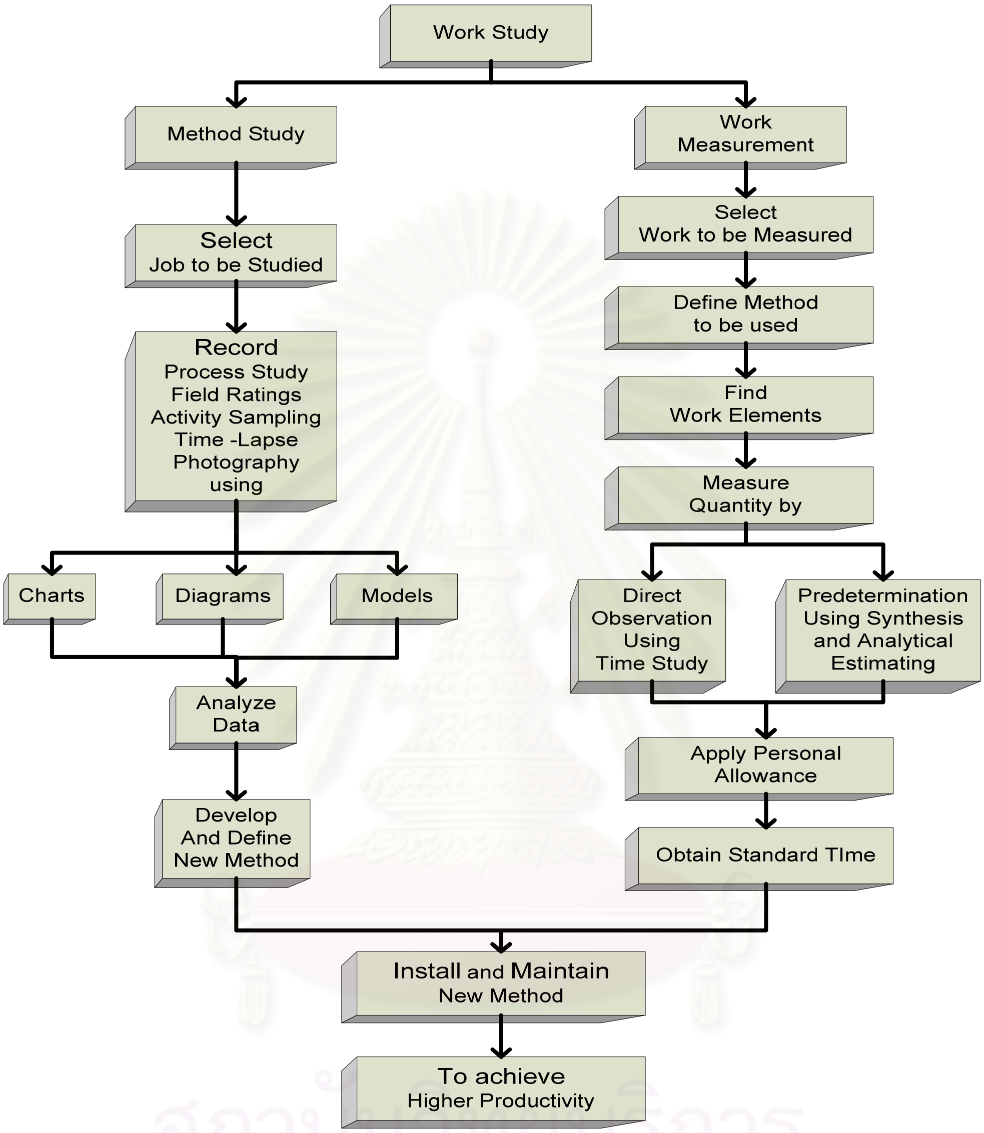


Figure 2.5 Work-Study Process (Drewin, 1985)

Those are used in the examination of human work in all its contexts, and which lead to the systematic investigation of all the resources and factors which affect the efficiency and economy of the situation being reviewed. It can improve work process efficiency. In addition, Thomas et al. (1990) revealed that work study wraps the process of observing, evaluating and improving performance in production operations.

Thomas et al. (1990) concluded that work-methods study (sometimes called a motion study) involved finding the preferred method of doing the work and work measurement or time study was used to determine the standard time to perform a given task. Figure 2.5 shows the relationship between the two. It is noticeable that both methods and work-measurement studies involve in-depth examinations of the production process. The best way to improve productivity is to study the way the work is performed, i.e., the work method (Thomas, Maloney et al., 1990).

2.2.3.1 Method Study

The British Standards defined method study as systematic recording and critical examination of the factors and resources involved in existing and proposed ways of doing work, as a means of developing and applying easier and more effective methods and reducing costs. Based on the viewpoint of Harris and McCaffer (2001), method study is used to record work procedures, provide systems of analysis and develop improvements. Moreover, this methodology will assist in project planning, site layout evaluating, temporary work designing, plant and other resources balancing at the work place, and the production re-planning and progressing.

Moreover, Harris and McCaffer (2001) pointed out that method study is useful in identifying symptoms in construction work through regular performance monitoring. Some of the result are resource to excessive labor overtime, bottleneck in the flow of materials, high materials wastage, frequent plant breakdowns, fatiguing work, late program, poor quality and workmanships, delays to and by subcontractors, excessive errors and mistakes, shortages of resources, insufficient information, site congestion, bad working conditions, cost overrun, high labor turnover, poor design of temporary works, and poor site layout.

2.2.3.2 Work Measurement (time study)

The British Standards defined work measurement as the application of technique designed to establish the time for a qualified worker to carry out a specified job at a defined level of performance. Supporting this idea, Harris and McCaffer (2001) defined work measurement, sometimes called time study, as the measurement of the time required to perform a task so that an output standard of production for a worker and/or machine might be established.

Moreover, they pointed out that the aim of the technique was the evaluation of human work and provided a fundamental part of the recording procedures described earlier under method study. However, the applications of work measurement data are extensive and can be used in:

- Determining suitable labor levels on construction activities,
- Setting standards of machine utilization and labor performance,
- Providing the basis for sound financial incentive targets, and
- Determining the most economic from alternative methods.

Since time study method attempts to quantify latter factors e.g., worker skills and equipment condition which interfere with standard conditions in order to establish the "proper" time for the job then it must have been measured in a planned environment, and not obtained from a disorganized site with inefficient working practice (Harris and McCaffer, 2001).

2.2.4 Conclusions on Process Improvement

One thing to be highlighted here is the fact that information is vital in process improvements. As discussed above about three approaches of process improvement, all those approaches are benefit to the process. Their promises are real, but only when the essential part is fulfilled which is information. Without information, nothing can be identified as constrains in performing work, tracked back as the problems origin, and done as a corrective action.

This information can be in many forms, it can be about the current practice of processes itself and others or even construction industry performance. This kind of information is called as feedback information. Mwamila and Karumuna (1999) affirmed that feedback information was useful information for continuous process improvements in identifying the problem origin and determining corrective action.

Regarding to several approaches in process improvement, few examples about the importance of feedback information for those approaches are given here. For example; benchmarking as a part of the systems approach, requires information of performance record from previous or other projects. Worker survey, a part of management approach, needs information about current practice to identify work's constraints. Furthermore, work measurement, a part of work task approach, requires information about time record in executing tasks.

Beside the feedback information, the other essential information for process improvement is related jobsite information along the process. It needs to be processed and delivered in a timely manner, accurate, and real time updated to streamline the decision making process.

The barriers occur in obtaining the information. The availability of certain information and time consuming tasks in capturing and storing information about the processes become a part of the barriers towards process improvement. In this sense, information technologies which offer many features to support the needs of information are required to support process itself and process improvements. How ITs support the process and process improvement will be discussed in the next section.

2.3 Information Technology Overview

In this section, several issues are discussed to provide the understanding of information issues in construction industry. This section starts with the importance of information in construction process. In this research the information is defined into two categories based on their aims namely feedback information (used for process improvement's approaches) and related jobsite information (used for streamlining process itself by enhancing process' decision making). Previous research of problems and benefits related to the presence of information in construction industry are discussed briefly. Problems in terms of information are needed to be solved and technologies with all their promises are seen as tools to support and diminish obstacles around the construction process. To support the above ideas, literatures which related to the current information technologies (ITs) applications in construction are reviewed here. Further discussions are revealed about RFID, one of new technologies, which will be proposed together with several ITs as new systems for improving prefabrication installation process. But before that, a brief introduction of barcode is presented as an overview of automatic identification and data collection system.

2.3.1 The Essence of Information in Construction

As mentioned earlier, information is essentially required for both the process improvement's approaches and the process streamlining itself. Feedback information is fundamentally required for process improvement approaches while related jobsite information (design, installation processes, etc.) is needed during the production processes to initiate processes. Therefore, the presence of information is becoming more important in producing a product and improving the process. The figure below illustrates the flow of both types of information (feedback and related jobsite information).

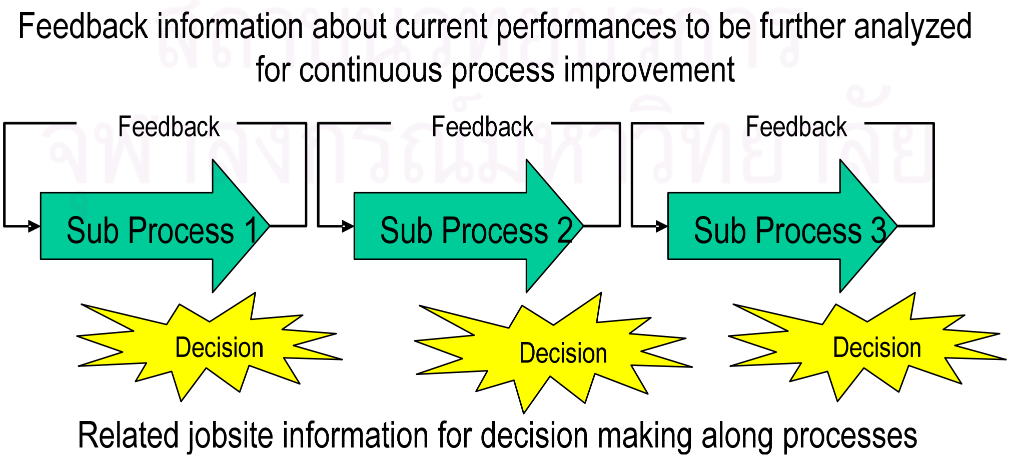


Figure 2.6 Two types of information for process improvement

Production information flow is defined by Winch (2003) as the flow of information required to produce the product from initial concept through to delivery to the customers. Information embedded in each phase of product life cycle to initiate and control the materials flow and processes through the life-cycle phases is defined below. Winch (2003) pointed out that construction products, one of many kinds of products which were produced by discrete assembly industries, experience a distinctive life-cycle of:

- Concept – the functionality of the product needs to be defined in relation to a particular market demand
- Design – the product needs to be engineered, and detailed – this information is typically captured in an engineering drawing
- Planning and control – the process of manufacture needs to be planned and then controlled against the plan
- Manufacture – the discrete components and subassemblies which make up the final product must be transformed from raw materials into their final form
- Assembly – the discrete components must be assembled to create the finished product

Gann (2000) stated that even though the amount of information required to produce a product was essentially the same today as it had been in the big day of the craftsman using hand tools but at present time each new producing phase required faster (the speed at which information is delivered and processed) information processing time. Based on the timing when the customer involved in the production of a product, as illustrated in **Figure 2.7**, Winch (2003) identified four generic production strategies as follows:

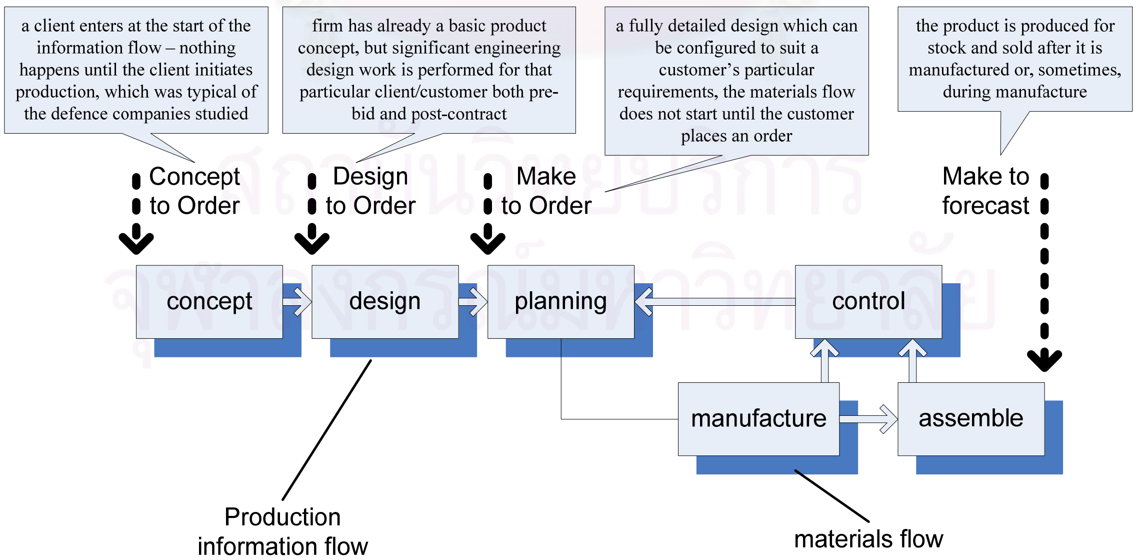


Figure 2.7 Products' life-cycle and four generic production strategies (adapted from Winch (2003))

Information has a great value if it is delivered in appropriate and accurate ways to the right people and place within the right time (Gann, 2000). In addition, he noted that it became a critical factor for success. Nesan (2004) pointed out that information which was also useful for learners if they were equipped with the complete and appropriate knowledge, skills, and recognition about job site that made them feel efficient, would result in an enhancement on productivity. This can be achieved since information eliminate knowledge gap-defining and knowledge gap-bridging strategies in an organization and learners will be able to deploy knowledge at job site so they can be more generative and productive.

Tucker (1986) discussed and addressed the following reasons impeding the construction processes in terms of the lack of information in construction industry:

1. The lack of simple reporting methods and clear communication procedures especially at the craft level.
2. The lack of fast feedback systems to accompany the growing tendency toward “fast-track” projects.
3. The increasing percentage of the time that management spends in obtaining field data and writing reports that all detract from the attention that could be devoted to actually managing the project.
4. The need for establishing strong project-team attitude” involves a wide variety of participants to jointly address significant project issues.
5. An overlook on the possible improvement of site operations during construction.

Some of the problems above are caused by the nature of construction process. The headquarter and project sites of a construction company are located separately and far apart. Especially, project sites are scattered and located in a remote area. This nature creates problems of obtaining information since paperwork is typically collected at jobsite, transferred to and processed at the main office, then reports are written and transferred back to the jobsite to be used by supervisors. Those activities are time consuming, thus create timeliness and accuracy problems and leads to the difficulty of obtaining accurate and timely jobsite information and record keeping.

Adrian (2004) described that management of construction needed more accurate and timely record keeping. However, time to process the necessary paper works takes away from the time to do construction work. Thus it needs technology to facilitate construction management such as barcode, digital cameras, fully integrated estimating and control systems, equipment guided by lasers and global positioning satellites, and internet-based technology in order to provide new ways to collect and utilize jobsite information. This information can be applied to improve productivity with automation and integration in processes. In addition, according to Adrian (2004) several benefits in getting and keeping the jobsite information accurately and in a timely manner enable:

- early identification of problems that can be solved to include productivity problems.
- consistent practices and procedures that enhance accountability and productivity.
- company office personnel to include the company owner “to see and monitor the job from the office”.
- preparation of financial statements that serve the needs of the company and external parties.
- collection of past project data that can be used to improved estimates and productivity for future projects.

Furthermore, they also provide:

- control on jobsite and company assets
- a paper trail of events, expected and unexpected, that can be used to prove and quality change orders, and can be used to prevent of quantify disputes or claims.

However, barriers in providing such important information possibly occur. As a result, they impede the process improvement. Time consuming tasks in capturing and storing information about current practices of the process become barriers in obtaining feedback information which is useful for three approaches of process improvement. The difficulty of obtaining accurate and timely jobsite information as well as record keeping obstructs the decision making process. Thus, construction industry has explored the possibility and eyed on information technologies as a solution to overcome these barriers.

2.3.2 Information Technologies for Process Improvement

The abovementioned problems need to be solved, either by using new technology or a creative reorganization of the existing technology. Nam and Tatum (1992) believed that problems pushed designers and contractors toward technological challenge and eventually lead to construction innovations. Moreover, they observed that some innovations could be categorized into two types which were “problem leads solution and technology guides problem”. For example, a project can not be carried out because the current technologies are not advanced enough to be applied to execute the work. A construction firm or engineering consultants try to conduct a research of develop brand new technologies. This innovation is called a problems-leads-solution type. On the other hand, if development of a certain concept enables the engineering consultants to apply this concept to a new project, then it is called a technology-guides-problem type.

Technologies, by providing faster feedback and accurate information and supporting concurrent decision making at a remote jobsite offer the possibility to improve inter-organizational networking. Moreover, Gann (2000) confirmed the assistance of technologies in facilitating the integration of information flows. For example, in the management of supply chains, it can save time for transferring and processing information, reduce the number of defects, and diminish rework items caused by problems such as the use of out-of-date information.

Computer technology as one of the widely used technologies that reforms the information processes in many construction activities. For example, automation in generating materials quantity takeoff which is produced by computer model; the constructability of design is tested before being built by using the 3D model; information can be exchanged readily; coordination can be made visually; and progress is reported graphically (Reinschmidt, Griffis et al., 1991; Atrostic and Nguyen, 2005). The features above strengthen Atrostic and Nguyen (2005) observation concerning computers which may affect productivity because they are a specific capital input of the production process. They are also used to organize or streamline the underlying business processes and substitute paper-based systems without changing the underlying business processes. Regarding the current computer technology, Reinschmidt et al. (1991) observed that rapid advances in computer technology enabled opportunities for innovation in communications. In addition, they have potential to transform the profession through the integration of the functions of engineering, design, construction, and facilities management that must come together to create a civil engineering project.

The implementation of computer technology opens the opportunity in the adoption of information and communication technologies (ICTs) in construction industry. According to Gann (2000), the rationale behind the adoption that is the ability to manage knowledge and information effectively and efficiently. This ability has been central to performance improvement in many industries and ICTs have often formed the underpinning technologies upon which new processes have been built. The adoption of information and communication technologies (ICTs) has offered the greatest potential for improving production processes which result from increasing speed and concurrence of decision making, the potential to make information readily available when and where it was required, and possibility to increase the visibility of decision making processes, including access to other people's decisions (Gann, 2000). In detail, He described the adoption of ICT that it had assisted firms in managing regular tasks relating to their internal business processes and supported project processes in design and management, by providing mechanisms for linking decision making from early planning and conceptual stages through design, engineering, and procurement to erection, installation, commission, and even operations and facilities management.

Gann (2000) noted that information technology (IT) has major impact on the construction industry which leads to an augmentation in productivity by:

- Reducing tedious, time-consuming, and inaccurate project paper work that characterizes the construction process.

- Enabling the collection of new information that should allow measurement of productivity to be improved, for example, corrections can be made and benchmarking can be performed.
- Improving project design documents by reducing or eliminating productivity delays due to errors and omissions.
- Connecting the project owner, designer, and constructor to be able to work collaboratively as a team to improve communication and information transfer.

In addition, Adrian (2004) pointed out that the use of new technology including bar coding, data imaging, 4D computer aided design (CAD) modeling, PDA's and smartboards, GPS (Global satellite system), and the internet has significant benefits on construction productivity.

Given that IT leads to an increasing in productivity, many studies have been conducted in the construction sector in recent years in order to investigate the relationships between IT and processes (as main component in production). Attempting to investigate the relationships, *Construct IT* (1995) produced an IT map that was related to the needs of construction processes without looking at the co-maturation of processes and IT. The IT map which shown in **Figure 2.8** has helped in identifying technologies which can support the process. These technologies have been classified into six main headings (Aouad, Kagioglou et al., 1999), which are as follows:

(1) *Simulation* (e.g. "what if", project simulation, economic appraisal).
(2) *Communication* (e.g. EDI, Internet).
(3) *Intelligence* (e.g. artificial intelligence, KBS, neural networks, case-based reasoning).
(4) *Visualization* (e.g. VR, 3D).
(5) *IT Support* (e.g. CAD, project planning, cost control).
(6) *Integration* (e.g. integrated databases).

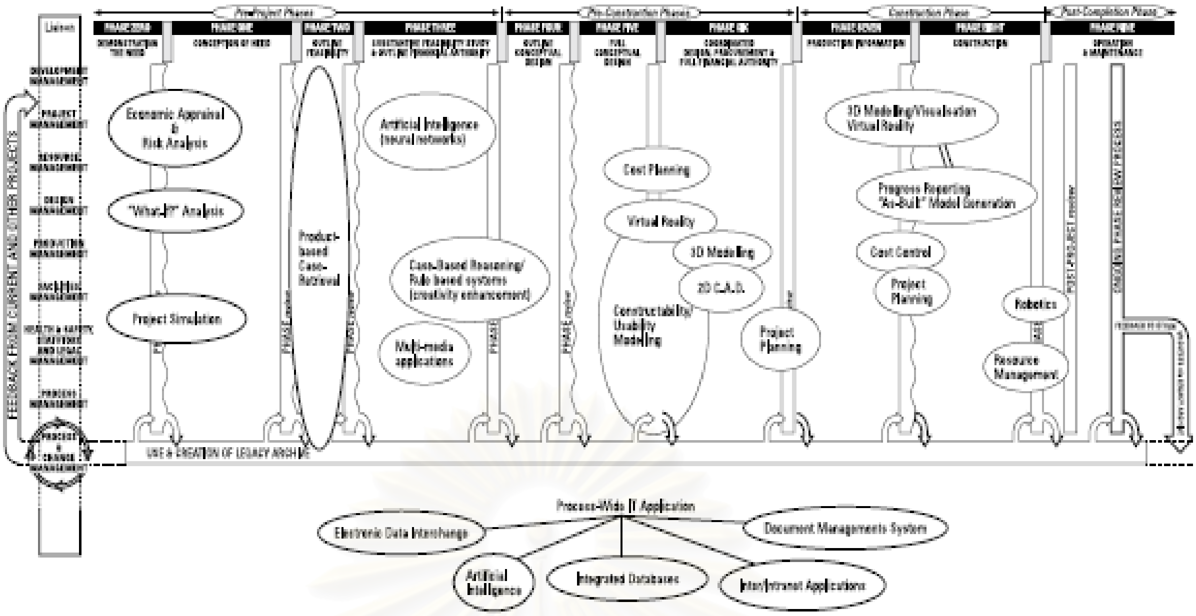


Figure 2.8 IT map (IT, 1995)

a. Simulation

Simulation which is the term given to the mathematical representations that take random samples from a probability distribution curve in order to simulate a real life situation is one of the appropriate methods for analysis of construction operations (Tavakoli, 1985). Furthermore, he pointed out that design of the model forces an analyst to examine all the elements of system in detail which might lead to a better understanding of the system and even to changes before simulation took place. This technology has been proved useful in reducing risk and uncertainty, and improving predictability in design decisions since it allows the user to experiment with different strategies without risk of disturbing the real system, meanwhile by giving insight into which variables are important and how they interact, simulation can serve as a teaching device (Tavakoli, 1985; Gann, 2000). Gann (2000) observed that simulation helped lower travel and other costs associated with making design changes as well as save time. On the other hand, Tavakoli (1985) noted that simulation had some disadvantaged for several reasons namely data interpretation could be subjective since simulation was not an exact science. Beside, simulation could cause excessive cost and model parameters might be difficult to collect or determine, and some relevant items might be left out inadvertently.

b. Communication

Electronic data interchange (EDI) and Inter/intranet are the example of communication technologies which allow all parties involved in a project to exchange information and support communication among them. According to Aouad et al. (1999), EDI and Inter/intranet applications such as e-mail, groupware and World Wide Web applications will help improve communications not only between the main parties involved in the project such as contractor, client and architect, but also between these main parties and suppliers and various legislative organizations, etc. Thus a better co-ordination and management of the project will be secured due to better communication.

c. Intelligence

The use of artificial intelligence (AI) could also help in various areas of the process. This is endorsed by Aouad et al. (1999) that noted technologies such as neural networks, case-based reasoning and knowledge-based systems could provide decision support systems that can manage and automate various processes within the protocol.

d. Visualization

Virtual reality (VR) and 3D are example of visualization technologies and used here as visualization tools for board members and higher management of the contractor and/or client so they can interrogate the VR or 3D model for detailed information on individual elements of the building and also allow them to see and monitor the progress of the project and interrogate the model for cost information (Aouad, Kagioglou et al., 1999).

e. IT Support

One of IT support technologies is CAD software which was useful in helping designers to coordinate basic geometric data, but it had limitations because it was not possible to manipulate data about other attributes, such as physical performance characteristics of component parts, shown in layered drawings. Software was needed that would enhance design and engineering activities by matching more closely the ways in which designers worked. This resulted in the concept of object oriented applications in which each data object (a part in building or structure) had its own data attributes. An increasing range of types of information could be attached to objects and used in different ways. This could potentially enable the calculation of a wide range of cost and performance functions (Gann, 2000).

f. Integration

Single project databases and new communications media, for instance, provided opportunities for virtually simultaneous decision making among project participants at long distance. Instead of project data being held on separate databases by each firm, the idea was to produce an electronic data model to which all participants could refer throughout the processes of design, construction, operation, and maintenance. These technologies introduced a new dimension to the integration of design and construction activities by changing the type of involvement of each participant, thereby altering the ways in which decisions were made. The timing, sequencing and hierarchy of decision making changed fundamentally (Gann, 2000). The task of developing better ways to share data was important, particularly if ICTs were to provide potential benefits of improved accuracy and speed of information flow between different project participants. The concept of single project database is emerged.

Six main headings of classification above resulting four IT application areas which are identified by Aouad et al. (1999) as commonly used IT in construction, as follows:

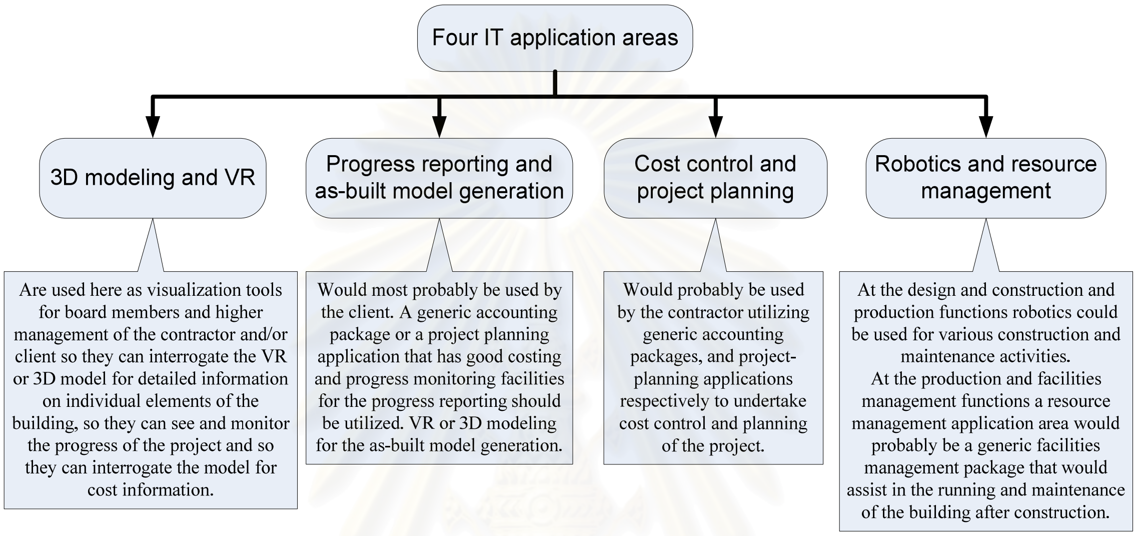


Figure 2.9 Four IT application areas (adapted from Aouad et al. (1999))

The latest issue of IT in construction industry and a blend of all IT application is computer-integrated construction (CIC) which defines a goal to make a better use of electronic computers to integrate the management, planning, design, construction, and operation of constructed facilities (Sanvido and Medeiros, 1990). Even though CIC is a relatively new concept, and is being implemented with different amounts of success, the manufacturing industry began work on computer integrated manufacturing (CIM) concepts decades before construction industry (*Integrated computer-aided manufacturing (ICAM)*, 1978). Sanvido (1990) observed there are four similar types of problems which have been experienced by both construction and manufacturing that motivated the CIC studies and being solved. Those are:

1. The high cost of correcting design errors and including changes late in the design stage or early construction/ manufacturing.
2. Poor resource utilization on fast-track projects.
3. Duplication of information in the same project, little information sharing, and lack of available planning information.
4. Poor efficiency in moving information from design to construction/ manufacturing.

Back to the nature of construction, conventional construction processes had usually involved sequential decision making, in which decisions were passed from one group of specialist professionals to the next, all of whom had to make inputs if overall project goals were to be realized. In this environment, decisions were translated and transferred in a process which changed semantics such that the original decision intent could easily be lost or altered. Multiple decision sequences of this type often took place with little or no possibility of assessing their validity against overall project objectives. Thus Gann (2000) found that new high speed digital communication networks offered the possibility of better links between clients, designers, construction organizations, and suppliers which originated from the recognition that these systems had the potential to provide an infrastructure for knowledge acquisition and accumulation, enhancing the possibilities of providing feedback and the potential to learn from previous experience.

2.3.3 Bar Code

Stukhart and Cook (1990) pointed out that an automatic identification system consists of a technology for automatically gathering information and a computer data-base system to manipulate the information. These systems include a means to automatically identify, track, locate, or status document, some individual or transaction item, and enter this information into a computer data base. The technology is currently available for automatic identification including barcodes, optical character recognition (OCR), radio frequency (RFID), magnetic stripe, and voice recognition.

A bar code can be defined as a self-contained message with information encoded in the widths of bars and spaces in a printed pattern (Harmon and Adams, 1984). Bell and McCullouch (1988) observed that bar codes permit rapid and error free data entry into virtually any type of computer system. Assuming that the typical bar code consists of 12 data characters, a bar code can be scanned by a handheld wand at least twice as quickly as the data can be entered by a skilled data processing operator using a keyboard. Whereas the keyboard data entry generally results in one error for every few hundred keystrokes, industrial bar code scanning is accurate to the order of only one error for several million characters entered (Allias, 1985).

2.3.3.1 Scanning Devices

Bar code scanners can be stationary of handheld devices tied to a computer keyboard (or communication terminal), or portable and programmable devices that capture and store the entered data. An inexpensive wand (light pen) reader can easily be connected to a computer keyboard through a “wedge”, permitting simultaneous entry of keyboard and bar coded data. A handheld laser reader is more versatile than a wand in that laser reader does not have to be in direct contact with the bar code being read. Portable devices, with a wand or laser reader attached, can be programmed to prompt the user for bar code and/ or manual data entry. The portable device stores the captured data (pertaining to a warehouse inventory, for example) which can then be loaded into a computer file at a later time (Bell and McCullouch, 1988).

2.3.3.2 ***Printing Devices***

Bar code symbols can be generated by commercial printing processes, by computer driven dot matrix printers, impact printers, thermal printers, laser printers, laser engravers, and other devices. Maintaining acceptable bar code print quality is an important element in all bar code applications. Inexpensive printing devices (dot matrix printers) may not produce reliable machine readable labels. As the result, typical problems encountered when using inexpensive printing devices including bar code roughness, voids in the printed bar, marks in the spaces between the bars, and low print contrast (Bell and McCullouch, 1988).

Over the years many applications have developed outside the grocery industry, such as in the fields of medicine, airlines, and manufacturing. Some major applications include production process manufacturing, inventory control, receiving, warehousing, automatic sorting and routing, updating of data bases, and inspection (Bernold, 1990). Moreover, Bell and McCullouch (1988) suggested several applications which are quantity takeoff, field material control, warehouse inventory and maintenance, tool and consumable material issue, timekeeping and cost engineering, purchasing and accounting, scheduling, document control, and office operations.

According to Leckenby (1984), six critical elements of a bar-coding system have to be investigated carefully before implementing bar code system. These are: bar code labels, bar code forms, data input, location of patterns, systems flexibility, and data integrity.

From the above discussion, bar code device provide the basic function to record data and data acquisition, however there are some limitations such as limited stored data and information can not be updated since the barcode only serves as pointer to more specific information stored in database.

2.3.4 RFID

RFID which use radio waves instead of light waves to read a tag can be viewed as a next development technology to bar code labels and the system typically comprises of the following components:

- A radio enabled device so called reader that communicates with or interrogates the tag for reading and writing by using at minimum, an antenna and scanner. Readers, often referred to as “interrogators,” can be either fixed-position or portable, just like bar code scanners (Intermec, 2003; Jaselskis and El-Misalami, 2003; Intermec, 2004).

- A tag or label that is embedded with a small integrated circuit chip and an antenna which are encapsulated in protective shell (Intermec, 2003; Jaselskis and El-Misalami, 2003; Intermec, 2004). The tag itself is an extension of the bar code labels you see everywhere today, but with more intelligence (Intermec, 2003; Intermec, 2004). In addition, Intermec (2004) pointed out the advantage of these more "intelligent" systems is that, unlike barcode-based data collection, an RFID system can read the information on a tag without requiring line of sight or a particular orientation. This means that RFID systems can be largely automated, reducing the necessity of manual scanning for exceptions management.

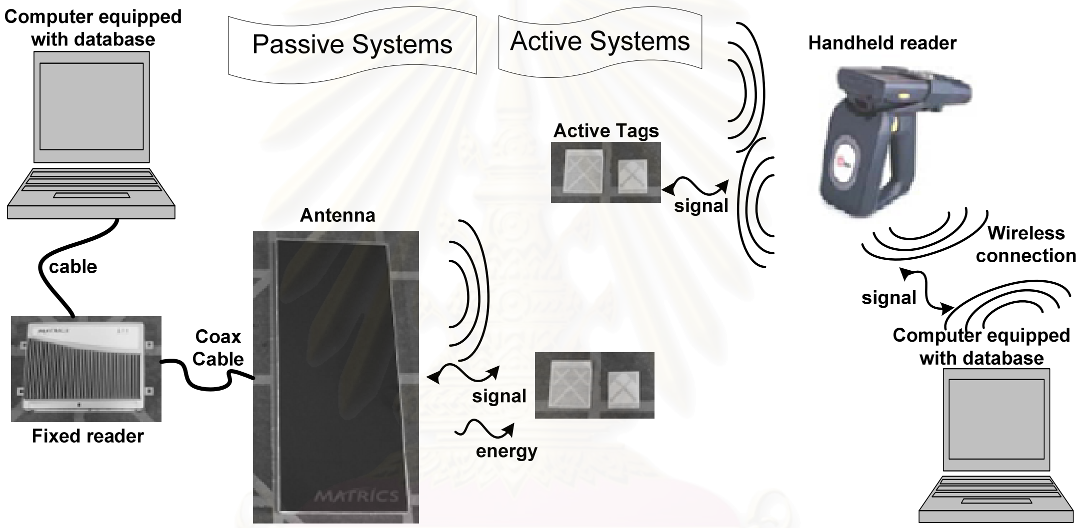


Figure 2.10 Current RFID systems

Various types of tags which are classified as seen in the following figure, are available for use in different environmental conditions.

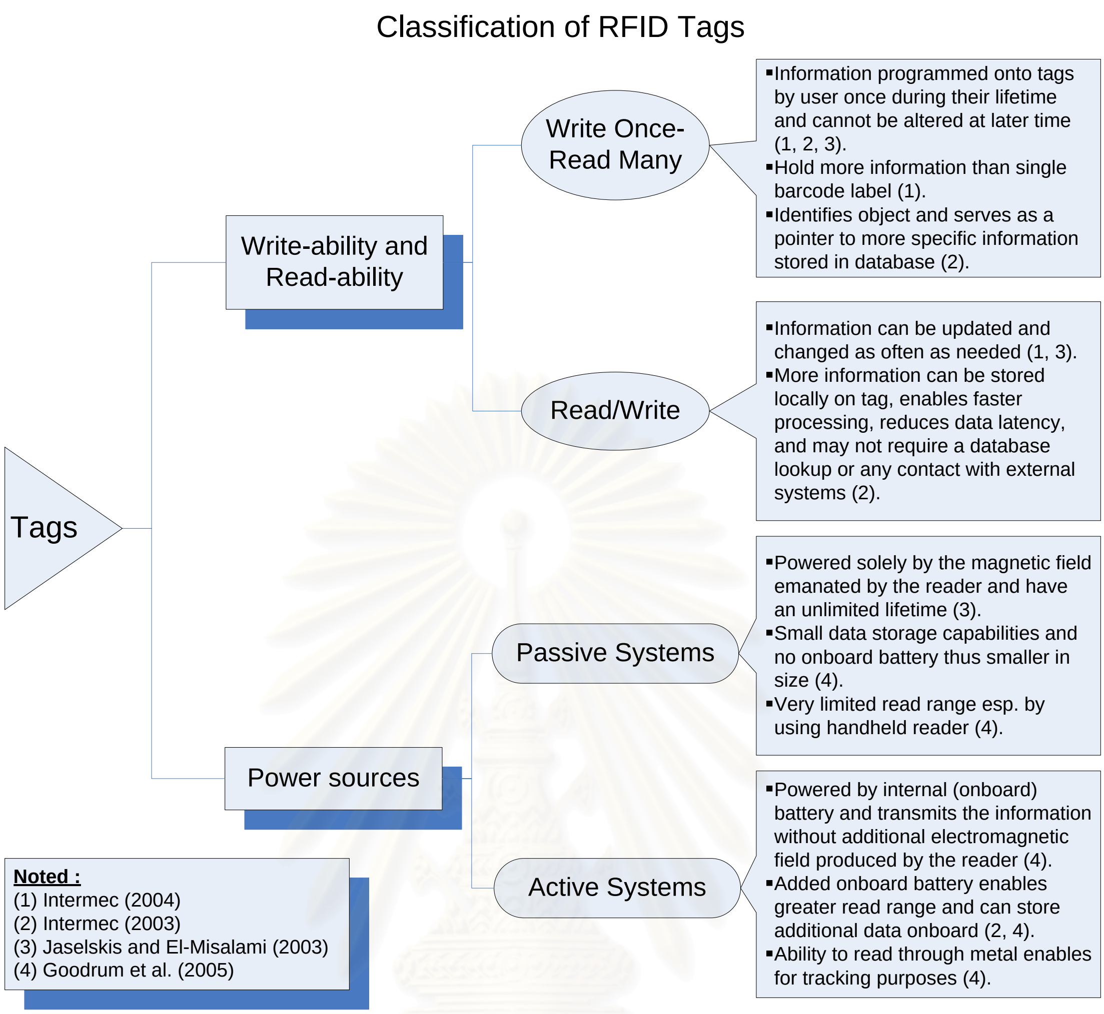


Figure 2.11 Classification of RFID tags

Intermec (2003) observed that the RFID system may boast an impressive reading rate of several dozen tags per second, but in a real-world scenario the processing speed is limited and dependent on the network and database. When the tag is read, the reader sends a message over the network to perform a database lookup to obtain specific item information necessary to complete the transaction. RFID provides the ability for high-speed, unattended reading of multiple tags. Tags have the ability to respond selectively based on the request of the interrogator. This has the affect of doing a group select on the tags, so that only the items you're interested in will respond. Moreover, Jaselskis and El-Misalami (2003) pointed out that RFID tags are classified as active, which means they include a battery, or passive, which means they are powered by the reader's energy field.

An RFID system's "read range" — the distance an interrogator must be from the tag in order to read the information stored on its computer chip — varies from a few centimeters to tens of meters, depending on frequency used, whether a tag is active or passive, and how directional the antenna is on the interrogator (Intermec, 2003). Moreover, Intermec (2003) described that for read/write tags, the read range is typically greater than the write range. Unlike bar code-based tracking systems, an RFID system can read the information on multiple tags without necessarily requiring line of sight and without the need for a particular orientation. That means RFID systems can be largely automated, greatly reducing the need for manual scanning.

2.3.4.1 ***<u>Possible Applications</u>***

Intermec (2004) noted that RFID is the ideal technology for automating manufacturing and distribution data collection processes. And because it can provide a portable database that lives with the product throughout its entire lifecycle, it can be used to store product genealogy data, including any after market adjustments/up grades. Having the complete history attached to the product could assist in minimizing warranty risk and optimizing the efficiency of a possible recall.

The six groups consisted of engineering/design, construction management, inverse manufacturing, material management, and field operations. Each groups generated several potential applications which can be seen as follows:

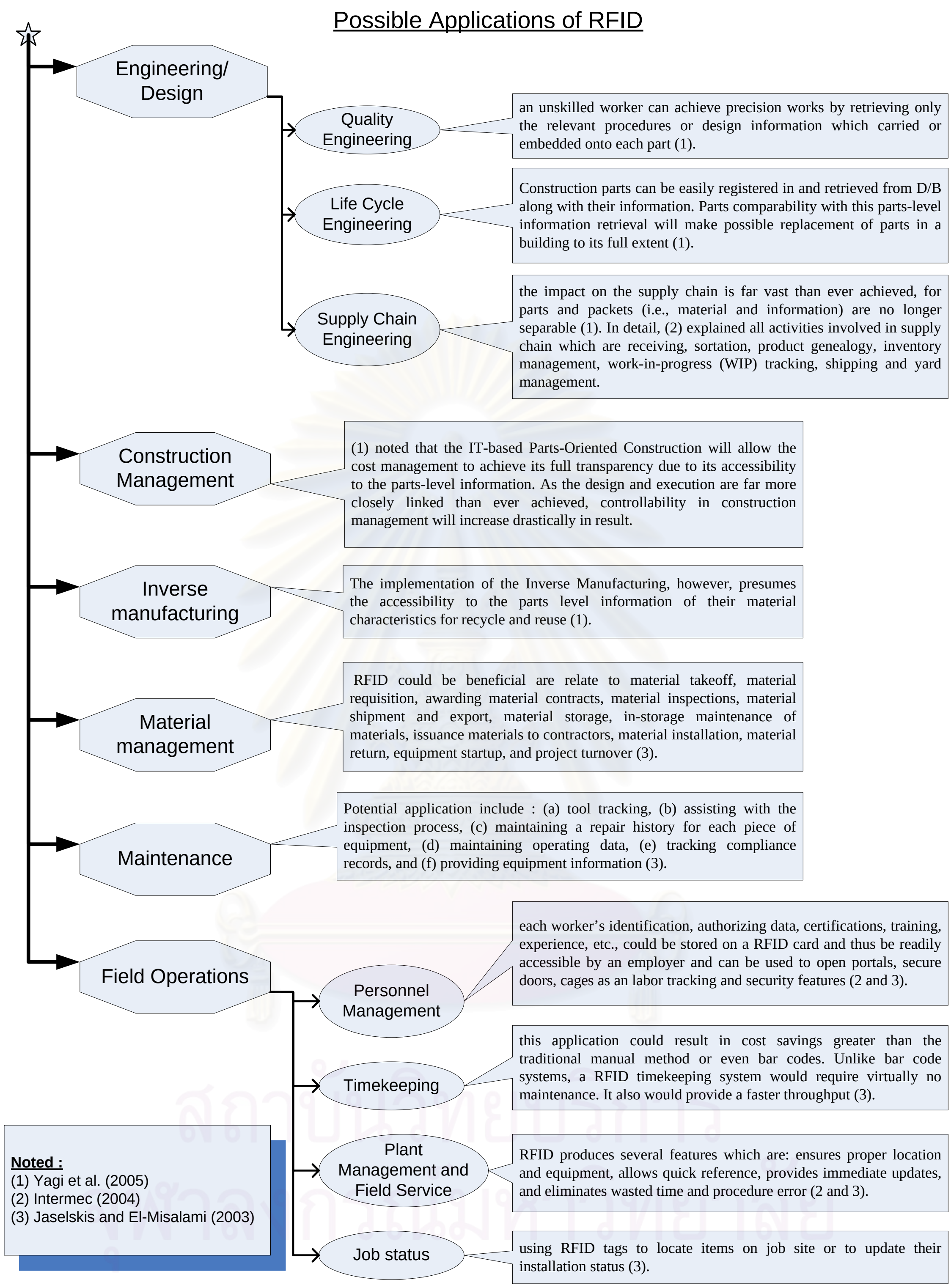


Figure 2.12 Possible applications of RFID

2.3.4.2 Benefits

Intermec (2004) described that RFID is a flexible technology that is convenient, easy to use and well suited for automatic operation. It combines advantages not available with other identification technologies: RFID does not require contact or line-of-sight between the reader and the object to be identified; can function in harsh environments; enables multiple tags to be read simultaneously; and provides a high level of data integrity. RFID can also provide security and product authentication because tags can be applied discreetly and are extremely difficult to counterfeit. Intermec (2004) also pointed out that RFID is a data collection technology that is relatively simple to deploy, integrates easily into existing data collection systems, requires minimal down time, and offers benefits and returns on investment that are beyond expectations. RFID technology:

- Carries dramatically more information than bar code labels
- Eliminates human error
- Improves speed and efficiency
- Increases information availability and location
- Allows enhanced security
- Delivers data with or without network connection

2.3.4.3 <u>Current Applications</u>

Jaselskis et al. (1995) observed that several RFID applications have been developed for transportation, manufacturing, law enforcement, and culture. Moreover, they explained that the applications involve many activities such as reading tags as an object passes a fixed scanner to record the movement of the object past the scanner, writing information on the tag that can be retrieved later, and retrieving information from tags at a distance using a mobile scanner. This expedites information gathering or finding misplaced objects because the operator does not have to go to the exact location of object.

These applications are discussed in the balance of this… and summarized in the following (K. Mead, … communication).

- Material identification: Parts and containers which contain materials can be efficiently identified by attaching a tag to each item. This can lead to more efficient warehouse management, material handling, assembly testing, and bill-of-materials matching. For construction projects in particular, material identification can reduce a great deal of confusion regarding arrivals of ordered supplies and their whereabouts at a jobsite.
- Tool handling: The embedded or attached tags are programmed with information on the tool name, its serial number, and information regarding maintenance and modifications. While lost, misplaced, and stolen tools are known to influence operating costs at a jobsite, lack of inventory control might also affect productivity rates more than actual labor force itself.
- Automatic-guided-vehicle (AGV) control: to allow AGV’s free operations in fixed locations. RF tag along the fixed travel paths can be used as path

"correctors". The tags can simultaneously communicate storage and transfer locations jobs, this RFID application might be beneficial to and increase the feasibility of the automated construction systems of the future.

- Tolls and fees: to collect users fees for the transportation of materials, equipment, and people. Vehicles equipped with FR tags pass scanners on the highway then automatically debit the requisite toll from an account.
- Hazardous material: to identify hazardous materials ate close range or from considerable distances in situations such as fires, natural disasters, or transportation emergencies.
- Meter-reading ID: to read water, gas, and electric meters from a safe distance by having a portable reading device pass by or be in the meter's vicinity. This also includes reading industrial meters such as those used in ground fueling operations for aircraft.
- Equipment maintenance: to read and write the maintenance history on FR tags while the equipment is in the service bay. This would greatly reduce paperwork related to factory warranties and time consuming maintenance logs. Examples include automobile warranties, maintenance schedules, and industrial-use histories.
- Personnel: to use in personnel identification and control systems, including a greatly expanded military dog-tag system, in which medical and personnel information is also stored.
- Asset location and tracking: to define the location of a specific, identifiable item during normal operations and to find objects that are misplaced or stolen. It also could be used to help construction project superintendents watch for expensive materials and tools leaving a jobsite. Automatic billing upon receipt of materials at a jobsite is also possible.

The followings are several things that can be concluded from information technology theme. Information has a great value if it is delivered in appropriate and accurate ways to the right people and place within the right time. The same things occur in construction industry. Information within any forms becomes a critical factor for success. Many problems around construction processes sourced from the lack of information. This issue has motivated construction firms and researchers to find out possible solutions to overcome the information-related problems.

Difficulty of obtaining accurate and timely information and record keeping are caused by time consuming activities that have to bear. Time consuming activities in obtaining information have created timeliness and accuracy problems. Problems need to be solved, either by using new technology or a creative reorganization of the existing technology. Technologies, by providing faster feedback and accurate information and supporting for remote and concurrent decision making, offered the possibility to improve construction processes.

Construction industry and researchers have eyed on ITs as promising solution to enhance construction processes. Many studies have been attempted in investigating the relationships between IT and processes. It started from mapping the ITs itself with the need of construction processes and classifying ITs into several main headings. It has explored the application of ITs into many construction phases to support their processes.

Currently, ITs have moved steps ahead to the automation and integration. It sourced from the need of construction management. It requires more accurate and timely information and record keeping. It needs technology to provide new ways to collect and utilize jobsite information. This information can be applied to improve productivity. It helps to improve the process improvements and streamline the decision making process.

Barcode and RFID are few technologies which are available for automatic identification system. An automatic identification system consists of a technology for automatically gathering information and a computer data-base system to manipulate the information. These systems include a means to automatically identify, track, locate, or status document, some individual or transaction item, and enter this information into a computer data base. The resulted information can be used for many purposes. This research will focus on the application of RFID and ITs as a form of automation and integration to support construction processes especially prefabrication installation process.

2.4 Research Gap

Related information along prefabrication installation process and feedback information of current prefabrication installation process practices are valuable for process improvement. This information helps to streamline the decision making processes and also process improvement. In precast installation process, this kind of information can enhance the process and indirectly has impact to the overall precast construction method productivity.

Problems related to that such information have arisen and impeded the attempt of process improvement. The unavailability of feedback information and the difficulty to capture and store information of current practices fence three approaches of process improvement. The usage of out of date, untimely and inaccurate related jobsite information impede the decision making process. Failure to provide such important information will be the basis of delay, dispute, cost overrun, and etc.

This research is trying to respond these problems (lack of information) by proposing a new information system. It aims to overcome those information related problems in precast installation process so that the construction industry can reap all benefits which are promised. This can be done by providing information along the process and feedback information with implementing ITs to support processes. Benefits of information technologies (ITs) are provable in supporting process management by reducing tedious, time consuming, and inaccurate project paper works. The proposed system includes RFID as automated identification and data collection together with ITs hopefully to enhance the information flow in precast installation process for both information along the process and feedback information.

2.5 Chapter Summary and Conclusion

Precast construction method precastrication is an industrialized construction technique originated from manufacture of construction materials and components. It has tried to answer several problems which are being faced by construction industry. Precast has responded with all promised benefits. However, prefabrication still has not fulfilled all those promises. Limitations occur and impede prefabrication performance. Precast construction method consists of two phases namely manufacturing and the assembly of precast components. Obstacles occur when the precast components have been transported to and assembly on construction. The natures of construction site become barriers to the precast installation process and affect to the precast productivity.

Many studies have attempted to enhance the prefabrication productivity. Based on prior research, several ideas are proposed to improve the productivity of prefabrication installation such as: designs, materials, quality control, and the effectiveness of process itself (process management). Many approaches to improve the productivity, but it has been proved that improving the process itself will bring significant effects to the productivity. One suggested three approaches to improve the construction process which are systems, management, and work task. Even though these approaches are very useful to enhance construction processes but they require feedback information of current process' practices for further analysis. Another idea is to streamline the decision making in processes. But still, it needs information along the process which is processed and delivered in a timely manner.

Thus information is essential to enhance the process. It helps the process improvement and the streamline of decision making in process. Barriers occur in obtaining the information in a timely manner and also capturing and storing information related to the process. Technologies, by providing faster feedback and accurate information and supporting for remote and concurrent decision making, offered the possibility to improve processes and the assistant in the integration of information flows. Many studies have been attempted in applying ITs to support construction processes. Now the technology development has moved to the integration of ITs. Barcode and RFIS are examples of automated input device for data collection. Together with ITs, barcode and RFID open the possibility of integration of automated data collection with the existing system.

CHAPTER III

RESEARCH METHODOLOGY

This chapter discusses about the methodology that was used in this research. The research was conducted in several stages. This research started by reviewing literatures and conducting field observations. These initial studies can be considered as preliminary works that are utilized as a basis in constructing a conceptual model. The conceptual model is then realized by exploring the RFID characteristics and the designing and developing the RFID system afterwards. Conclusions and recommendations based upon the findings are made and presented at the last section. The details of each stage are presented on the next sections of this chapter.

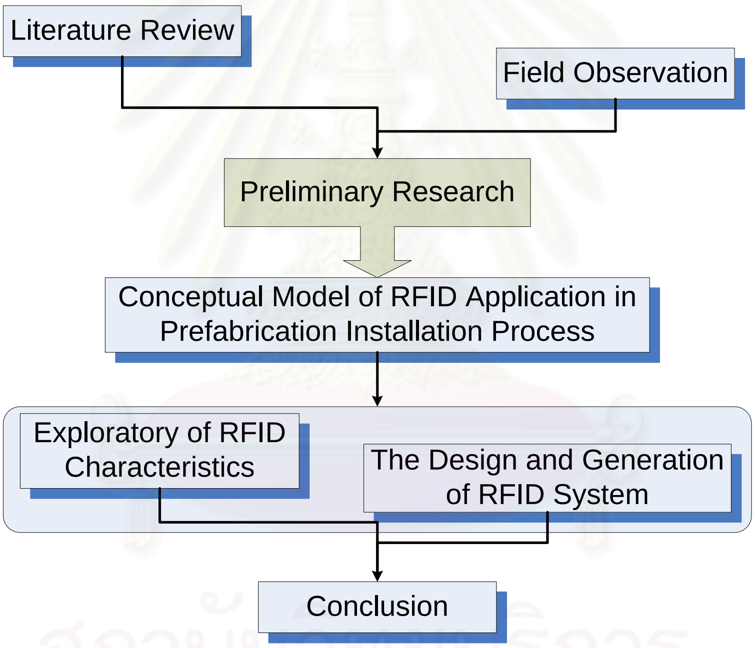


Figure 3.1 Research Methodology

3.1 Literature Review

In this research, literature review is performed as a means in finding an alternative way to improve construction processes. Thus, related literatures are reviewed to present basic knowledge about prefabrication construction method, process improvement, information technology, and RFID. After reviewing the literatures, information is found as an essential part in processes' improvement. By providing certain information that can help streamline the process, process improvement can be achieved. Information technologies (ITs) have been seen as a promising tools to provide such information in a timely manner and accurate manner.

The prefabrication (precast) installation process in housing projects is selected to be the case study. Precast construction method is the state of the art in construction industry. It benefits the construction industry and offers many advantages but still has been challenged with barriers when the components are being assembled on site. The high performance of the precast manufacturing which is performed in a factory cannot be followed by the assembly phase due to the nature of on site construction.

Then, attempted to verify that information can streamline the process through ITs, this research has seen the aforementioned circumstances as a good start to exercise process improvement in terms of information. The divided and discrete components allow the RFID tag to be attached on the panels. Information about a particular panel can be retrieved from the database and updated by using an RFID system.

RFID as the latest technology in automatic identification and data collection is being examined together with IT applications to support construction process in terms of information. By providing related jobsite information in a timely and accurate manner along the process, decisions can be made responsively and promptly. The resulting feedback information facilitates the management in evaluating the current performance. These two types of information will streamline the precast installation process.

3.2 Field Observation

Field observation is conducted to complement the literature review. It presents a description about the current practice of precast installation process in housing projects. By doing field observation, an in-depth study about the problems in installing precast can be performed. It facilitates analysis of the feasibility in implementing RFID system into the construction site and to see how the system will perform in supporting the process by providing particular information.

As observed from the field, information has become an essential part to the precast installation process. The precast installation process requires information to support its processes. The required information can be classified into three based on the involved parties which are namely: the manufacturer, the management, and the crew at the construction site. The crews at the construction site require information such as required preparation activities, installation sequences, how to handle it (i.e., lifting phase and installation phase), and changes that have been made on the panels to support them in performing their works. The management requires information of current work progress. The management can manage their production strategy in response to the current work progress to achieve certain goals and trace the problems origins from the current performances and solve the problems afterwards. The manufacture requires information about the needs of the construction site about the panels so that they can provide and transport the required panels prior to installation schedule.

The aforementioned information can be classified into two based on their usage, namely; related jobsite information and feedback information. Related jobsite information encompasses information that is instantly required for decision making process. Most of the previously mentioned information is incorporated to related jobsite information. Whereas the feedback information is defined as information related to current work progress which enables the management to evaluate the current work performance during construction, trace the root of problems, and formulate solutions to be implemented.

Currently, these two types of information are difficult to obtain. The unavailability and difficulty to capture and store the information of the current practices have become the impeding factors in obtaining feedback information. Apart from that, the out of date, untimely, and inaccurate information have hindered the advantages of providing related jobsite information as if it is delivered appropriately along the process.

3.3 Preliminary Research

As mentioned in the Literature Review, process becomes the key in achieving higher productivity. A higher productivity can be achieved by looking into the process, evaluating the current process to gain feedback and conducting a continuous process improvement. Process improvement is found as a method of productivity improvement given from the facts that it improves information flow, minimizes waste of labor hour, and reduces productivity loss.

However, the process improvement entails feedback information and related jobsite information along the process. Feedback information is useful in identifying the problem origin and determining corrective action. Whereas related jobsite information is very helpful to streamline the decision making process if it is processed and delivered in a timely and accurate manner.

As generated from the field observation, the precast installation process is currently experiencing barriers in obtaining those two types of information to improve its process. The precast installation process has realized the importance of these types of information. The availability and time consuming tasks in capturing and storing the information about the current practice of precast installation process have impeded efforts towards process improvement. In addition, the out of date, untimely, and inaccurate related jobsite information has become barriers in commencing the works and decision making process.

Therefore, improvements upon precast installation process can be made by providing these two types of information. ITs (information technologies) have been observed as promising solution to overcome those information barriers. Information technologies (ITs), by providing faster feedback and accurate information and supporting for remote and concurrent decision making, offered the possibility to improve precast installation process.

Thus an information system which is comprised of the use of radio frequency identification (RFID) as an automated identification tool integrated with a database is proposed to support the precast installation process. RFID system is utilized in obtaining feedback information and providing related jobsite information that can be used for process improvement.

3.4 Conceptual Model of RFID Application in Precast Installation Process

The previous section has stated that information is found as an essential element for process improvement. Information Technologies (ITs) can facilitate the needs of process improvement. An information system which is named as the RFID system is proposed for process improvement upon prefabrication installation process. RFID as the latest ITs in automatic identification and data collection will be integrated with several IT applications (database, 3D, and communication) to support precast installation process.

The conceptual model presents the possible application of RFID and its possible benefits to prefabrication installation process. The current practice of precast installation process is identified prior to proposing the conceptual model. Depart from the current practice of prefabrication installation process, the conceptual model is proposed in line with the existing processes.

By identifying the needs of related jobsite information along the process and feedback information, the conceptual model of how the RFID system can merge with and support the existing precast installation process is constructed. The RFID system provides related jobsite information for the involved parties to support them in performing their tasks. In addition, the RFID system generates feedback data which is essential information for the management in identifying the root of problems on the current practice and finding the solutions.

To fully accomplish the benefits of the RFID application in precast installation process, there are two subsequent works that have to be conducted within this research. Firstly, the exploration of RFID characteristics is expected to give a basic knowledge of RFID characteristics and as guidance before implementing the RFID into construction industry. The exploration of RFID characteristics generates the best usage of RFID system to meet the needs of RFID application in supporting precast installation process. Secondly, the designing and developing of RFID system which conveys the conceptual model of RFID application to the end users in the form of user interface. The user interface enables end users (i.e., foreman-engineer, management, and manufacturer) in accessing, obtaining, and updating the related jobsite information to support their works as illustrated in the conceptual model. The generated information can be perceived as the related jobsite information and feedback information which are essential for process improvement.

3.5 The Exploration of RFID Characteristics

Before going further with RFID application, it is essential to know the basic characteristics of RFID. Therefore, through the Exploration of RFID Characteristics, the characteristics of RFID are explored to its limits. In addition, several simulations are conducted to meet the needs of RFID application to precast installation process. General characteristics are identified and unique characteristics are presented as guidelines in implementing RFID to meet the needs of the proposed application.

The characteristics of RFID are investigated in two stages. The first stage investigated the RFID characteristics for the general usage. The first investigation encompassed the followings series of tests:

- Maximum reading distance,
- The readable coverage area at certain distances (range from maximum to 0.5 meter (m) in front of vertical plane and with 0.5 m interval between distances) and its behavior from distance to distance,
- Behavior of the coverage area if the reader is horizontally rotated clockwise and counter-clockwise at certain angles (30^O, 45^O, and 60^O) and vertically rotated in angles 30^o and 45^o incline upwards,
- The successful reading rate of those coverage areas,
- Maximum amount of detected tags at once at certain distances,
- Minimum distance between two tags that can be read separately at certain distances,

Whereas at the second stage, simulations of the on-site precast panels' arrangement are carried out to find the best usage of RFID application in precast installation process. The second investigation incorporated the series of tests as follows:

- Maximum reading distance from simulation of precast panel's placing (1 panel) at three directions (front, 45^o angle, and side),
- Behavior of the placing combination from 2 tags that are mounted on different panels which are vertically separated at distance 0.2 m (current practice on case study), and
- Simulation of the interaction between 3 tags that are attached on different panels which are vertically separated at distance 0.2 m.

As the expected results, the effects of the tag orientations, the tag positions, the working distance, the interrogation angle, and the presence of the other tags (interference) are subjected to the investigation. General conclusions are made upon the general characteristics whereas the unique characteristics are utilized as corridor in implementing RFID. It is suggested that the working area and the interrogating method should comply with the unique characteristics.

3.6 The Design and the Development of RFID System

As previously mentioned, the precast installation process is currently experiencing barriers in obtaining the two types of information to improve its process. A system that can obtain feedback information and provide related jobsite information towards process improvement is essentially required. Therefore, RFID System is proposed to support prefabrication installation process by overcoming the barriers in obtaining those types of information.

Several stages are carried out in designing and developing the RFID System. It is started with the identification of the involved parties and their requirements upon information along the defined precast installation process. The defined series of process can be translated into three main events, namely: the departure, the arrival, and the installation. On these three events, the involved parties have to be identified prior to the identification of the required information. Depart from the identification of involved parties; the identification of their requirements upon information and both of the providers and the users of the required information have to be made.

The results will be the basis in determining the framework of RFID System which is composed of three main modules, namely pre-input, input, and output. The modules should reflect the sequence of the series of process. Information that relates to the properties of precast panel which can be defined prior to the departure event and either by the manufacturer and the management is perceived as a pre-input. The input itself is defined as the information that is collected along the three defined events. The collected data is then stored at the database and when the involved parties are in the needs of accessing the information, it will be presented informatively in form of reports and basic analysis to support the precast installation process. Both forms of the information are perceived as the output of RFID System. As the possible usage of generated information to the identified users is identified and presented afterwards.

3.7 Conclusions and Recommendation

To sum up the presented chapters, conclusions are made upon the parts of this thesis. It started from the motivation and the objectives of this research consecutively. A brief description upon the methodology in conducting this research is presented afterwards. The conclusions upon the findings of each of the stages which are incorporated within the methodology and the recommendations are presented in the last section.

CHAPTER IV

CONCEPTUAL MODEL OF RFID APPLICATION IN PREFABRICATION INSTALLATION PROCESS

This chapter aims to present the possible applications of RFID in prefabrication installation process in the form of a conceptual model. The current practice of precast installation process is identified prior to proposing the conceptual model. Based on the current practice of prefabrication installation process, the conceptual model is proposed in line with the existing processes. The possible benefits that can be perceived as expected benefits from the application of RFID in precast installation process are identified and presented. To fully accomplish the benefits of the application on RFID in precast installation process, there are two subsequent works that have to be conducted within this research.

4.1 Background

As previously mentioned in the review of related literatures, the process becomes the key in achieving a higher productivity. An effort to improve the process requires two types of information which are related jobsite information along the process and feedback information. In the current practices, although these two types of information are essential for process improvement, construction process has faced barriers in obtaining this information. The unavailability and difficulty to capture and store the information of the current practices have become the impeding factors in obtaining feedback information. Apart from that, the out of date, untimely, and inaccurate information have hindered the advantages of providing related jobsite information as if it is delivered appropriately along the process. In this regard, the construction industry as well as the other industries has relied on technologies (information technologies) as promising solution to overcome those information barriers.

Similar with the other processes in construction industry, prefabrication installation process also requires both types of information to streamline its process. Precast installation process has seen information technologies (ITs) as a strong solution in responding the needs from both types of information. ITs are capable to deliver related jobsite information in an accurate way, a timely manner, and updated to commence the works and in the decision making process. In addition, ITs assist in providing feedback information and saving time to capture and store this type of information.

Therefore, a conceptual model of the ITs application in prefabrication installation process is proposed within this research. RFID as the latest ITs in automatic identification and data collection will be integrated with several IT applications (database, 3D, and communication) to support precast installation process. RFID system is expected to provide those two types of information for process (i.e., precast installation process) improvement.

4.2 The Objective

This research aims to apply RFID as one of the latest ITs in automatic identification and data collection for construction process improvement. This research uses prefabrication installation process in housing projects as a case study. The main reason behind the selection of this case study is the use of discrete parts in the form of precast components (panels). In prefabrication (precast) construction method, the building structure is divided into parts (panels) which allow the RFID tag to be attached onto panels whenever they are manufactured. Related information that can help streamline the processes can be embedded into the tags. This will enable the integration of information from design to installation stage. Using the same analogy with the application of barcode on retail industry, the attachment of RFID tag onto component (panel) will help to do automatic identification, data collection and monitoring the jobsite’s latest status. The new information system so called RFID system consists of RFID integrated with a database. RFID system is utilized in obtaining feedback information and providing related jobsite information that can be used for process improvement.

4.3 Scope of the Conceptual Model

Though prefabrication construction method incorporates at least two main stages (i.e., manufacture and construction site) which are characteristically different from each other, this research mainly focused on prefabrication installation processes at the construction site. As previously mentioned in the review of related literatures, the processes at manufacture that are relatively under the controlled conditions and sheltered environment perform better than processes at construction site. Therefore, the research aims to improve the processes at construction site to achieve a higher productivity for overall processes involved within precast construction method.

Several processes are defined and incorporated within this conceptual model. The series of processes are commenced from the departure of precast panels from the manufacturer, the arrival of the precast panels at the construction site, the storage of the precast panels, and the installation of the precast panels. The installation of precast panel is started from the selection of precast panel, the lifting phase, and ended when the precast panel is placed into its installation point.

The application of RFID system into these series of processes is hoped to support prefabrication installation process. By providing related jobsite information along the process and feedback information, a streamlined precast installation process can be achieved.

4.4 Methodology

Three phases are involved in constructing this conceptual model, namely: identification the current practice, the conceptual model of prefabrication installation process, and the identification of possible benefits from the conceptual model. The current practice of prefabrication installation process has to be identified prior to the conceptual model. The information that will be resulted in identifying the current practice of precast installation process can be perceived as a guidance to trace how the RFID system can support the existing process. Therefore, the proposed conceptual model is in line with the current practice. The possible benefits that can be gained from the realization of conceptual model are identified and presented afterwards.

4.5 Current Practice

This section presents the current practice of precast installation process in housing projects. Starting from the truck's arrival on the construction site, the panels are removed into A-Frame which is located near the installation point. A particular house has its own A-Frame which can hold all the required panels to assemble one complete house. The panels are arranged randomly but its arrangement concerns the A Frame's stability. After all panels are placed into the A-Frame, the next activities are preparations before installation, the installation itself, and the joints installation. All these activities will be repeated for the first and second floor.

Several activities that need to be done prior to installation are considered as preparation activities. The slabs have to be marked to provide working lines. The adjusting bolts which are installed on the top of the first floor beam have to be adjusted by surveying the vertical alignment. The crane itself has to be placed in certain locations which have to secure the visibility to all installation points.

When installation comes, the desired panel has to be found first. The desired panel will then be lifted up from the A-Frame onto the installation point. At first, the panel will be placed near the desired installation point. At that place, the joints have to be pulled out from the panel. Then, the panel will be placed onto the installation point. Until the supporting jack is installed, the panel is still being held by the crane. The hook is then released from the panel and adjustments have to be done. Horizontal alignment and the panel's tilt have to be checked and adjusted. Finally, the vertical alignment has to be checked and adjusted.

The activity is continued by joints installation. Two types of joint are implemented here. Welded joint is used for joints between inner panels whereas cast in place joint is utilized for joints between outer panels. For cast in place joint, the rebar has to be inserted through pulled out joints. The gaps between panels are covered by using PU (Polyurethane) and filled with concrete by grouting from the top and dowel holes.

This research has limited the installation process up to the placement of the precast panels onto installation points. The joint installation will be out of the research's concern. The new information system has focused to help the installation process which is defined since precast's departure from manufacture until its placement onto installation point.

4.6 Conceptual Model

This conceptual model of RFID works in this case study aims to describe one from many applications of RFID in construction industry. A new information system makes use of radio frequency identification (RFID) as an automated identification tool integrated with a database is proposed in this chapter. Within this case study, the RFID system will be implemented into two phases as shown in **Figure 4.1**. The first phase stretches from manufacture to precast stockyard; the second phase stretches from precast stockyard to installation point. This system automatically identifies prefabrication (precast) panels, collects and records their related data (work sequences, panels handling, and installation time) to a database, and monitors the status (real time) of jobsite performances.

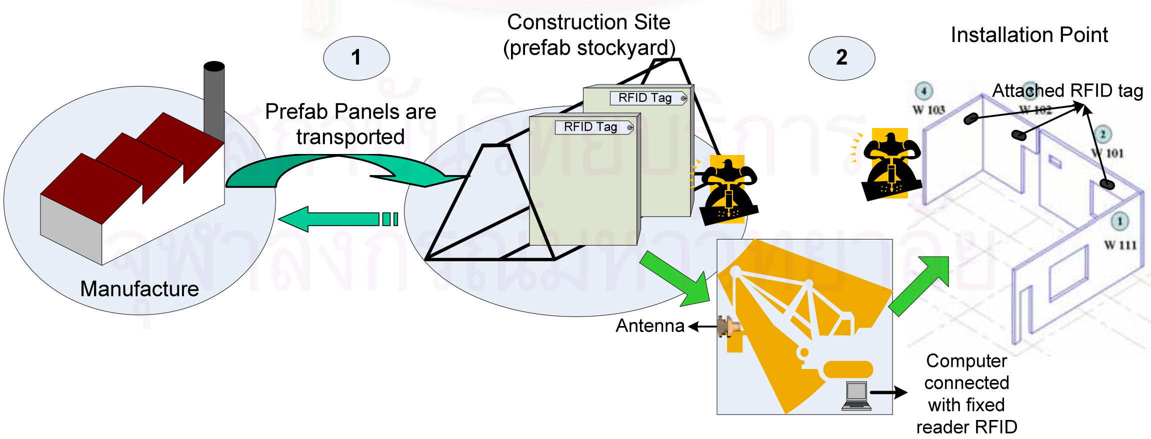


Figure 4.1 Conceptual model of how RFID works in this case study

This new system aims to support precast installation process by providing related jobsite information to enhance the decision making process and provide feedback information that can be used for further analysis for process improvement. Both types of information are very valuable to streamline the process. Basically the application of RFID in this case study is to automatically identify and collect the data to monitor and support prefabrication installation process. The following sections will discuss a new proposed information system that conceptually can support prefabrication installation process.

4.6.1 Manufacture – Precast Stockyard

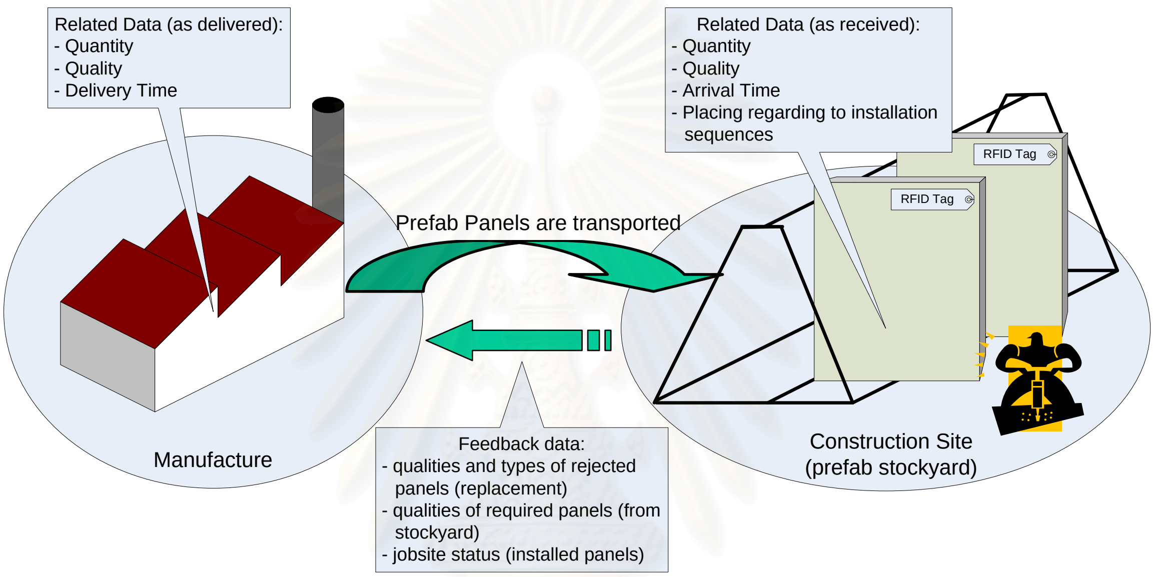


Figure 4.2 The involved data along manufacture to precast stockyard

The above **Figure 4.2** describes about how the RFID system can support the delivery process. RFID tags can be attached as soon as panels are produced. The attached RFID tag contains information that is related to jobsite information. For example: panel information regarding to the installation of associated panel to a particular house (which house does the panel belong to?), the quality as it departs from manufacture, and delivery time. These information details can be represented by direct information that can be embedded into tags or by codes as identification (ID) number that is associated to some information that can be retrieved from database. When precast panels arrive at the construction site, data that is related to the arrival can be uploaded to the database directly. The RFID readers which can be in fixed (in form of portal) and portable reader (hand held form) will interrogate (identify) the received panels and collect their data. Information related to the quality, quantity, and arrival time will be added into database. The storage of precast panels is arranged based on their associated location regarding its installation sequences. This kind of information can be retrieve from a database when the RFID system identifies the panels. In case of damaged and rejected panels, the status of the quality (accepted, rejected, and damaged) and its ID number can be uploaded to the database. The quantities of installed, damaged and rejected panels are reported as feedback to the manufacturer and the report can be useful in making decision for the associated party. In the case of damaged panels, authorized parties are aided in making decision about the damaged panels whether they can be repaired or needs to be replaced. Manufacturers use the report to send the new panels and the replacements before installation time which will eliminate delays since panels are available and ready to be installed. The information can be delivered and processed in a short time by using an integrated database. By comparing the information related to quality, quantity, and timing between delivery and arrival, the related problems described along these stages can be identified and further analyzed to improve the process.

4.6.2 Precast Stockyard – Installation

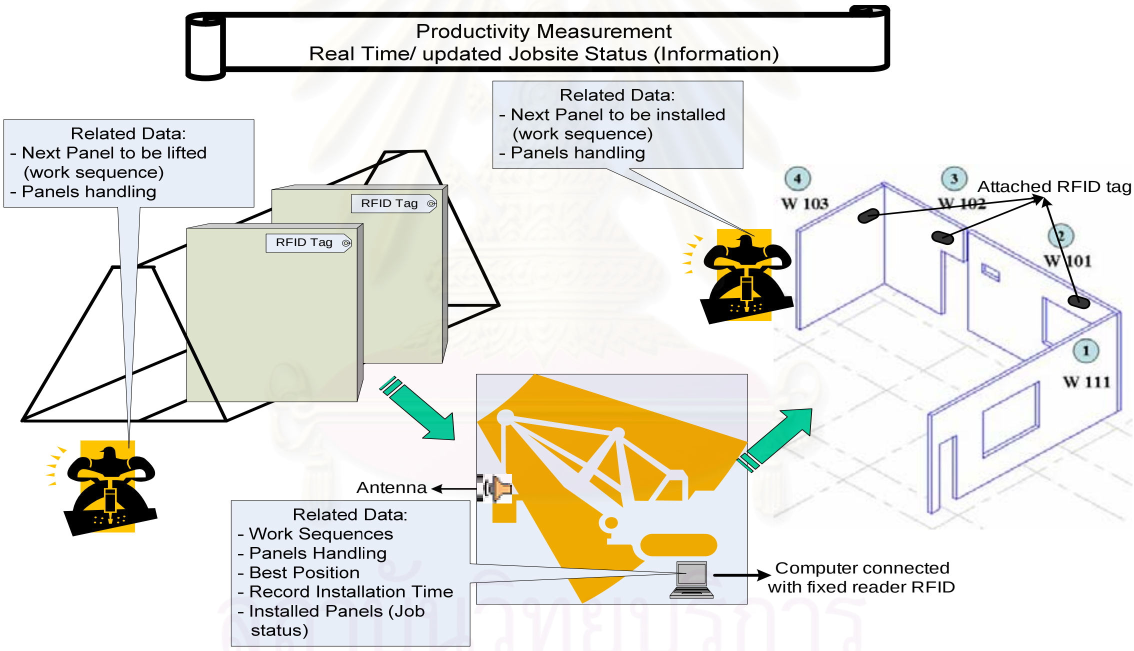


Figure 4.3 The involved data along precast stockyard to installation point

The application of RFID in precast installation process aims to support the process by obtaining feedback information and providing related jobsite information that can be used for process improvement. As shown in the above **Figure 4.3**, the process starts when the crane lifts up the selected panel according to its sequence. The foreman by using a handheld reader retrieves the data from the database about the next panel that will be lifted and how to handle the panel lifting. Equipped with this information, the foreman can arrange and instruct the laborers to prepare and execute the work. Meanwhile, the crane operator can retrieve information related to the work sequence (next panel to be lifted), panel handling (lifting phase), and best position to do lifting. The new information system will inform the next panel to be lifted and tracking the associated panel. The crane operator can move the boom which is equipped with an RFID antenna to scan through the panels and stop at the place where system found the correct panel. At the same time, the foreman at the installation site by using handheld reader can retrieve information from the database related to work sequence and panels handling (installation phase). After receiving the related information, the foreman can arrange and instruct laborers to prepare and execute the work. Information related to the work sequences and panels handling is presented in 3D form. Assisted with the laborers standing by near the correct panel, the crane lifts the panel to the installation site where the laborers are standing by to do the installation. Crane operator can record the installation time starting from lifting and installing each panel by using this system. When installation of current panel has finished, crane operator have to confirm so that the system can collect data and generate reports about the installed panel and its installation time.

4.7 Expected Benefits

The expected benefits and associated benefited parties are identified and presented in this section. Information from the RFID system and generated reports can be used for many purposes. Different users utilize different information and are benefited differently.

The RFID system assists the manufacturer, management and engineer/foreman in doing their works. For manufacturer, information from generated reports determines which panels have to be produced and delivered to reduce the risk of inventory shortage. For the management, information from the generated reports helps to monitor the work progress whether it is on time or behind schedule. Management makes use of the RFID system to record the installation activities and evaluate its performance to identify the problem origins and determine corrective actions. For the foreman and crane operator, the information from the RFID system helps them to enhance coordination in executing the work and increases their learning. The details of expected benefits at manufacture – precast stockyard phase and precast stockyard – installation point phase are shown in the **Figure 4.4** and **Figure 4.5** below, respectively.

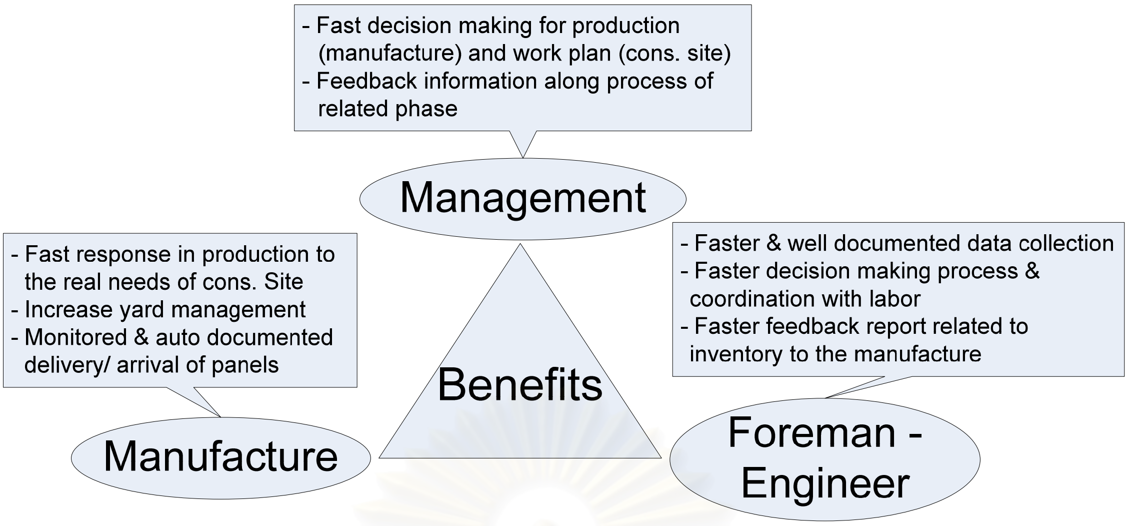


Figure 4.4 Expected benefits of RFID system in manufacture – precast stockyard phase

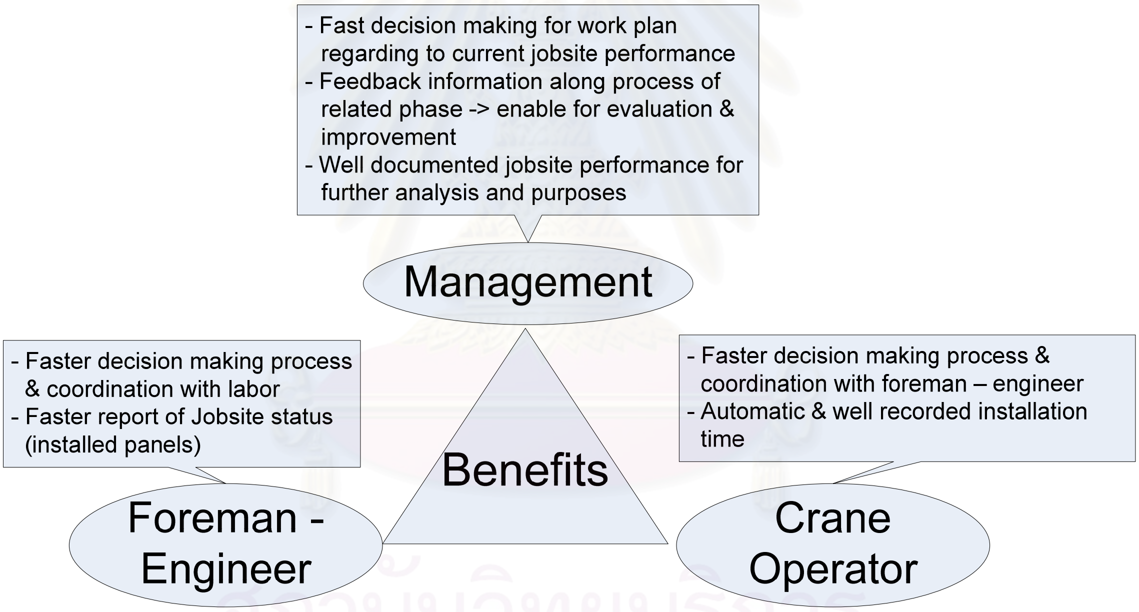


Figure 4.5 Expected benefits of RFID system in precast stockyard – installation point phase

Obviously, the RFID application in prefabrication installation process conceptually benefits the construction industry. The expected benefits lead to a higher performance of all involved parties in performing their tasks.

4.8 Post Conceptual Model

The proposed conceptual model of RFID application in prefabrication installation process can be fully accomplished by proposing the best usage of RFID and developing the RFID system. Therefore, The Exploration of RFID Characteristics and The Design and Development of RFID System are presented as Chapter 5 and 6 respectively to follow up the proposed conceptual model.

The Exploration of RFID Characteristics aims to explore RFID characteristics to its limits and provides basic knowledge about RFID characteristics as guidance in implementing RFID into construction industry, particularly precast installation process. Therefore, a series of tests had been conducted to investigate the RFID characteristics and few simulations had been carried out to find the best usage of RFID system to meet the needs of RFID application in supporting precast installation process. As a result, a resume of RFID characteristics and recommendation of the best usage of RFID application are presented within this chapter.

The Design and Development of RFID System aims to deliver the conceptual model of RFID application to the end users (i.e., foreman-engineer, management, and manufacturer) in the form of User Interface of RFID System. By designing and developing the RFID System, end users can interact with the RFID System through the user interface. End users will be able to perform their task along the precast installation process as conceptually illustrated in the previous section. The RFID System enables the end users to interrogate (i.e., identify) the panel and access and update the panels' information (i.e., data collection). Further processes on the generated results of RFID System will be identified and presented to show the usefulness of the results for process improvement.

CHAPTER V
THE EXPLORATION OF RFID CHARACTERISTICS

This chapter aims to explore more about the characteristics of RFID which are investigated through several stages to support the RFID application into construction industry towards process improvement particularly precast installation process. The first investigation is about the readable coverage areas of the RFID tags, the reliability, maximum number of detected tags, and minimum distance between tags that can be read separately. The details of each RFID characteristics are presented in the scope section. These characteristics are tested on a plane which is perpendicular to the reader. Then the second investigation is carried out to simulate the on-site precast panels' arrangement. These simulations are conducted to generate the best combination of tag placement to meet the current practice of precast panel storage. The aforementioned RFID characteristics are presented and analyzed to construct guidelines in using RFID technology into construction industry. Suggestions and conclusions of applying RFID into construction industry, particularly precast installation process, are presented in the last section.

5.1 Background

The application of Radio Frequency Identification (RFID) as a form of automation is a relatively novel issue in the construction industry. Its applicability and benefits to construction projects have been explored in recent years. Apart from the applications and benefits of RFID, it is essential to recognize the characteristics of RFID. Lack of knowledge on RFID characteristics has become an impeding factor for its applications into construction industry.

Not knowing the basic RFID characteristic (e.g., max. reading distance, coverage reading area, etc.), researchers cannot fully maximize the applications of RFID into construction industry. Few researches have strived in revealing RFID characteristics before going further with its application. Investigating the RFID characteristics is an essential aspect alongside the construction needs in determining RFID applications into construction field.

The explorations of RFID characteristics are expected to provide guidance for researchers in applying RFID into construction industry. Various RFID characteristics can be in form of advantages and limitations to be fully utilized for the benefits of construction industry. Some applications can apply the advantage of RFID; some can deal with its limitations; and some need to combine both.

5.2 The Objective

The exploration of RFID characteristics which is conducted through a series of tests has the following objectives:

- Explores RFID characteristics to its limits.
- Provides basic knowledge about RFID characteristics as guidance in implementing RFID into construction industry, particularly precast installation process.

It is expected that the results will help researchers to have a better understanding on RFID characteristics before going further into its application to construction industry. Researchers will be able to fully maximize RFID characteristics based on its advantages compared with other identification technologies and its limitations to meet the needs of construction industry.

5.3 Scope of the Testing

As previously mentioned in chapter 2 (Literature Review) particularly on RFID's section, the RFID reader regarding to its mobility can be divided into two types which are fixed reader and portable (handheld) reader. The series of conducted tests are limited to handheld reader because the portable reader is the most suitable RFID reader for the proposed RFID application into precast installation process. The RFID is involved in data collection activity which demands high mobility. To support RFID application into precast installation process, it is essential to investigate RFID characteristics specifically for handheld reader. Therefore on the next section, will be discussed types of RFID characteristics that are investigated through a series of tests.

Among the many types of RFID characteristic, this research focused mainly on just several of them. Certain types of RFID characteristic are essential as guidance in proposing RFID application into precast installation process. The followings are the types of RFID characteristics which were investigated (note that the orientation of tag both horizontal and vertical is one of characteristics which are investigated and the following characteristics are subject to these orientations):

- Maximum reading distance,
- The readable coverage area at certain distances (range from maximum to 0.5 meter (m) in front of vertical plane and with 0.5 m interval between distances) and its behavior from distance to distance,
- Behavior of the coverage area if the reader is rotated clockwise and counter-clockwise at certain angles (30^{O}, 45^{O}, and 60^{O}),
- The successful reading rate of those coverage areas,
- Maximum amount of detected tags at once at certain distances,

- Minimum distance between two tags that can be read separately at certain distances,
- Maximum reading distance from simulation of precast panel's placing (1 panel) at three directions (front, 45^o angle, and side),
- Behavior of the placing combination from 2 tags that are mounted on different panels which are vertically separated at distance 0.2 m (current practice on case study), and
- Simulation of the interaction between 3 tags that are attached on different panels which are vertically separated at distance 0.2 m.

5.4 Methodology of the Testing

Generally, the series of tests which were conducted in this experiment can be classified into two phases. The first phase series of tests aims to obtain and analyze the basic characteristics of the RFID handheld reader. The resulted and analyzed characteristics were used as concerning aspects in conducting the second phase series of tests which is simulates the placing of precast panels. These simulations aim to obtain best combination of tag placement on the panels to meet the needs and current practice of precast installation process.

The outline of how these tests were performed is shown in the **Figure 5.1** below.

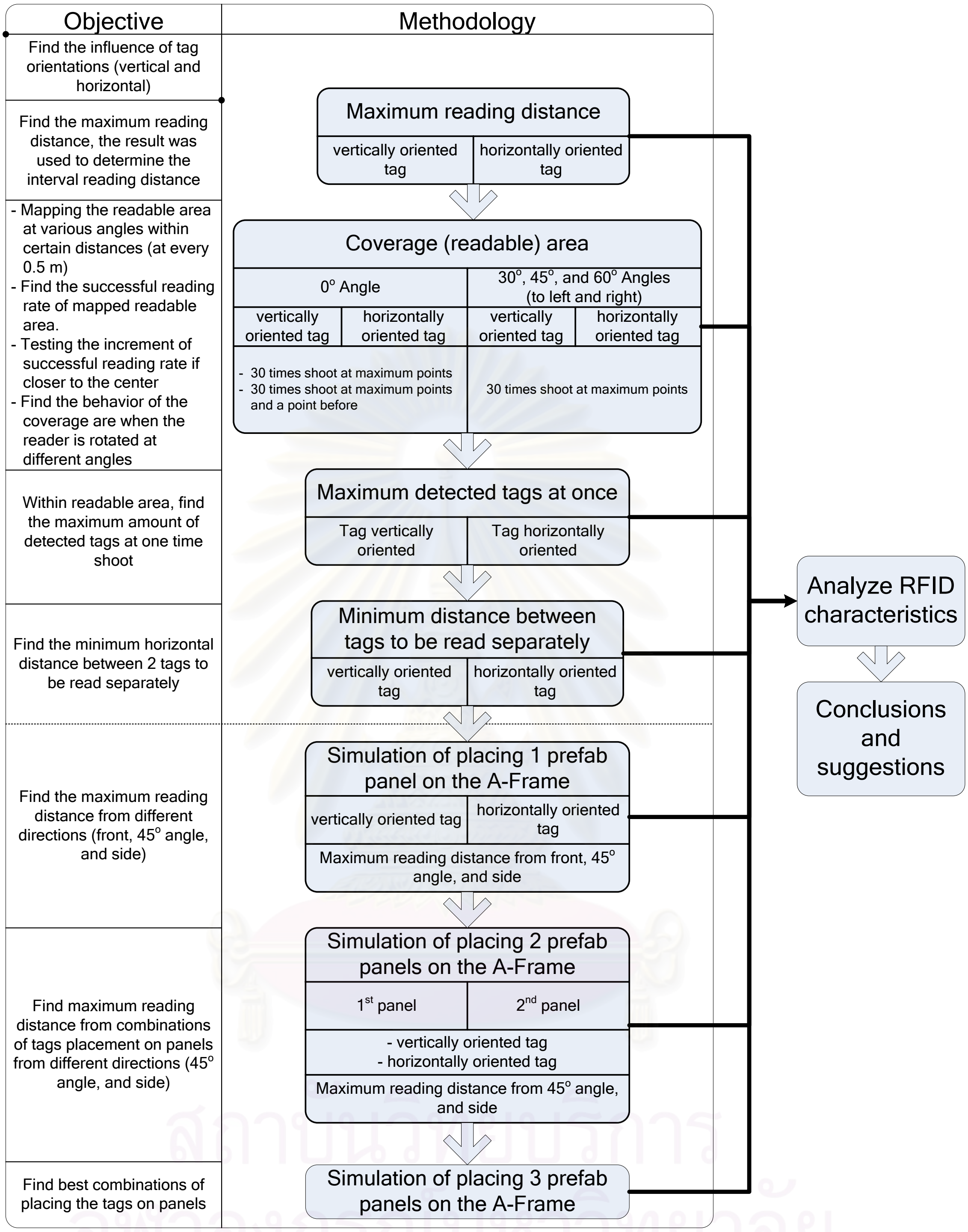


Figure 5.1 Methodology of exploring RFID Characteristics through a series of tests

5.5 Media and Equipment

The materials needed to conduct the series of tests are composed of several elements which are media and equipment. As seen in **Figure 5.2** below, the tags will be mounted on a media, a wall made from Styrofoam 4.2 m in width and 2.4 m in height. The Styrofoam is selected as the material for media because of its neutrality. It does not absorb the Radio Frequency (RF) wave as much as other materials do. Preliminary investigations were carried out in selecting the suitable materials as media. Brick walls and metals do absorb the radio wave since both materials yield very short reading distances, ranging from 0.5 m to less than 1.6 m. The light weight wall made from gypsum material yields maximum reading distance up to 2.29 m. Styrofoam yields 2.4 m as maximum reading distance, therefore it was selected as the test material. Note that the reading distance is measured based on horizontally oriented tags.

Horizontally Oriented Tag

Figure 5.2 Styrofoam wall as a media where the tags are mounted on and the tag

As previously mentioned, a portable reader was utilized in conducting these series of tests. The portable reader is produced by Intermec and consists of Intermec 700 Series Color Mobile Computer and IP3 Intellitag Portable Reader (UHF). These two components communicate by using infrared interface. The general specifications of this equipment are listed in **Table 5.1** below:

Table 5.1 Specifications of Intermec 700 Series Color Mobile Computer and IP3 Intellitag Portable Reader (UHF)

Specification	Descriptions
Intermec 700 Series Color Mobile Computer	
Communications	Infrared, Bluetooth, Local Area Network (LAN), and Wide Area Network (WAN)
Operating System (OS)	Microsoft Pocket PC
Identification Feature	Bar code scanner
IP3 Intellitag Portable Reader (UHF)	
Physical Characteristics	
Weight without 700 Series Color	0. 48 kg with battery
Weight with 700 Series Color	1.04 kg with battery
Standard Features	
Communications Interface	Infrared data connection to 700 Color
Antenna	Internal, circularly polarized
Identifies	Up to 6 tags per second
Memory	Can retain up to 100 tag ID’s
Notes : Rates and ranges will vary by tags spacing, movement, mounting surface, surrounding materials, and orientation	

The portable reader had been modified to meet the needs of the tests. Light modifications had been made prior to the series of tests. The first modification was made to the base of the portable reader. It was modified to allow the reader to be mounted on a tripod as seen in the **Figure 5.3**. The result is to place the height of the antenna about 1 m above ground. The attachment of the portable reader on the tripod allows the rotation in the horizontal and vertical axis. **Figure 5.3** shows horizontal and vertical scales were mounted on the portable reader.

Figure 5.3 From left to right: Portable reader was attached on a tripod, 3D view of portable reader, horizontal scale for horizontal rotation, and vertical scale for vertical rotation

For the tests’ usage, there was no modification made to the user interface of the portable reader. The series of tests used the standard user interface to read and write the tags. The standard user interface allows choosing whether to read a bar code label or read and write RFID tags. As described in **Figure 5.4**, whenever the trigger is pulled, the tags' codes within its readable range and the amount of detected tags will appear on the screen.

Figure 5.4 The appearance of standard user interface on Intermec 700 Series Color Mobile Computer

5.6 Maximum Reading Distance

The first test aims to obtain maximum reading distance that is yielded from both tag orientations. From preliminary test, it was concluded that the horizontally oriented tag yield reading distance shorter than vertical ones. Aimed to compare the performances of those two orientations under the same test conditions (means the same distance), the shortest reading distance was selected as the furthest reading distance for both tag orientations. Then it was found that the maximum reading distance for the horizontally oriented tag is 2.4 m whereas for the vertically oriented tag it was 2.6 m. This 2.4 m distance then was set up as the maximum reading distance as well as a benchmark in determining a proper distance interval. By using 0.5 m as interval between shooting points, as shown in the Figure 4.5 below, there were five shooting points (at distances 2.4 m, 2.0 m, 1.5m, 1.0 m, and 0.5 m) along the path. These distances were used to collect data of RFID characteristics within the next series of tests (as shown in **Figure 5.5** below).

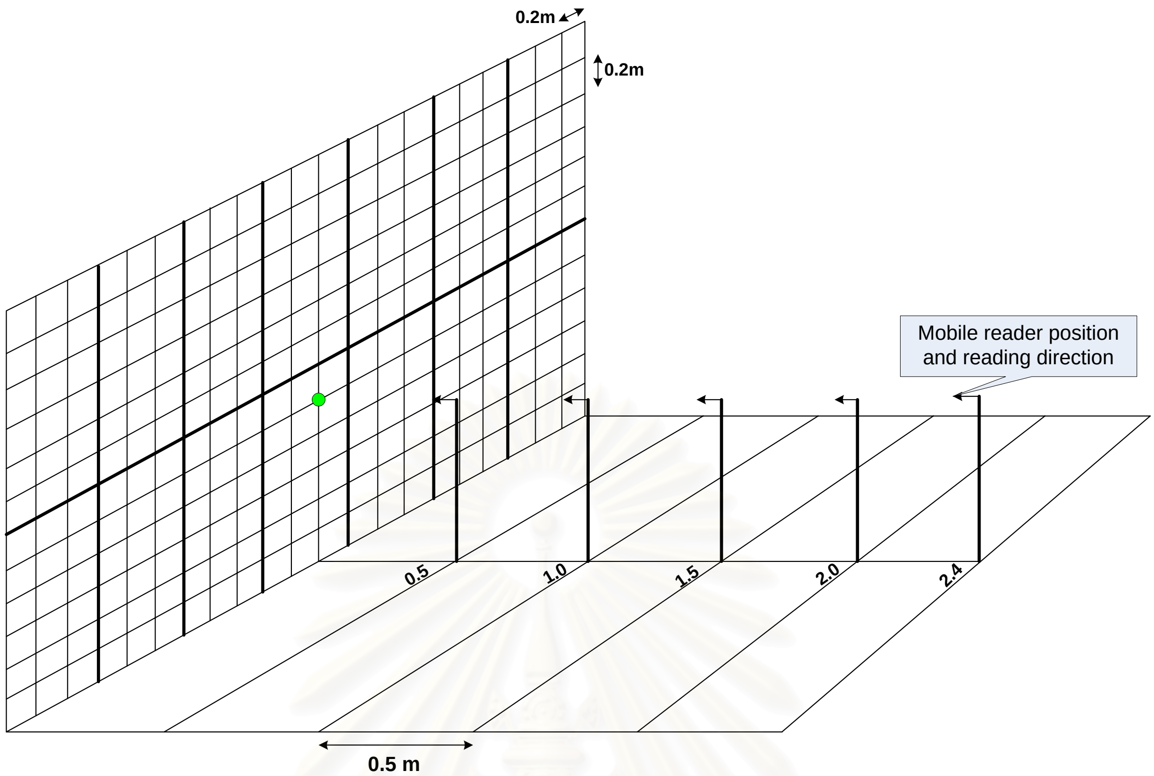


Figure 5.5 Distances where the portable reader was placed at 0.5 m interval up to maximum reading distance

5.7 Readable Coverage Area

These series of tests aim to map the readable coverage area given different scenarios. Basically there were three types of tests which were conducted under coverage area tests. For every distance, there were 18 coverage areas that had to be investigated. Nine series of tests were conducted on vertically oriented tag, the rest were subject to horizontal ones. These nine series of tests were comprised of seven and two tests of horizontal and vertical rotations respectively.

Perpendicular position between antenna's polarization direction and Styrofoam wall was established as 0^o angle of the reading. Referring to **Figure 5.6**, a point had been set up as a center; 1.0 m from the ground which is the same height as the of portable reader's antenna. At 0^o angle, signals were shot to the wall where the tag is mounted on. The tag was moved both vertically and horizontally in every 0.2 m to find the maximum readable area that will be mapped on the wall (as described in the **Figure 5.6**). These activities were repeated until a complete coverage area is formed.

Then 30 times shot were carried out to each of the maximum points which consists of maximum up, down, left, right, upper left, upper right, lower left, and lower right. This test aims to obtain the successful reading rate of the formed coverage area by taking the maximum points as samples. Another test was conducted but only to 0^o angle; another 30 times shot were performed to each point before the maximum point. The test was performed to determine if the closer distance to the center will give a higher successful reading rate.

Referring to 0^o angle as the center line for both horizontal and vertical rotations, the coverage areas were yielded whenever mobile reader was rotated horizontally (in angles 30^o, 45^o, and 60^o to the left and right) and vertically (only in angles 30^o and 45^o incline). The formed angles were measured from center line (0^o angle) with the portable reader's stand points as the center of rotations.

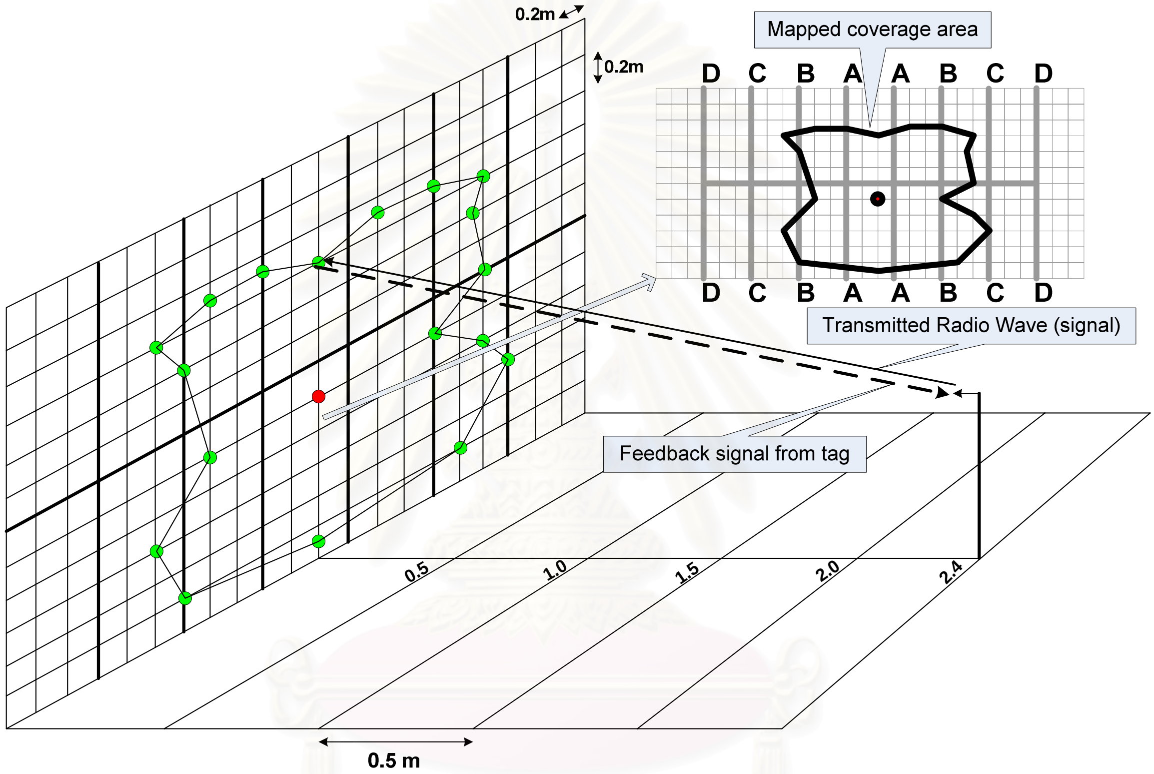
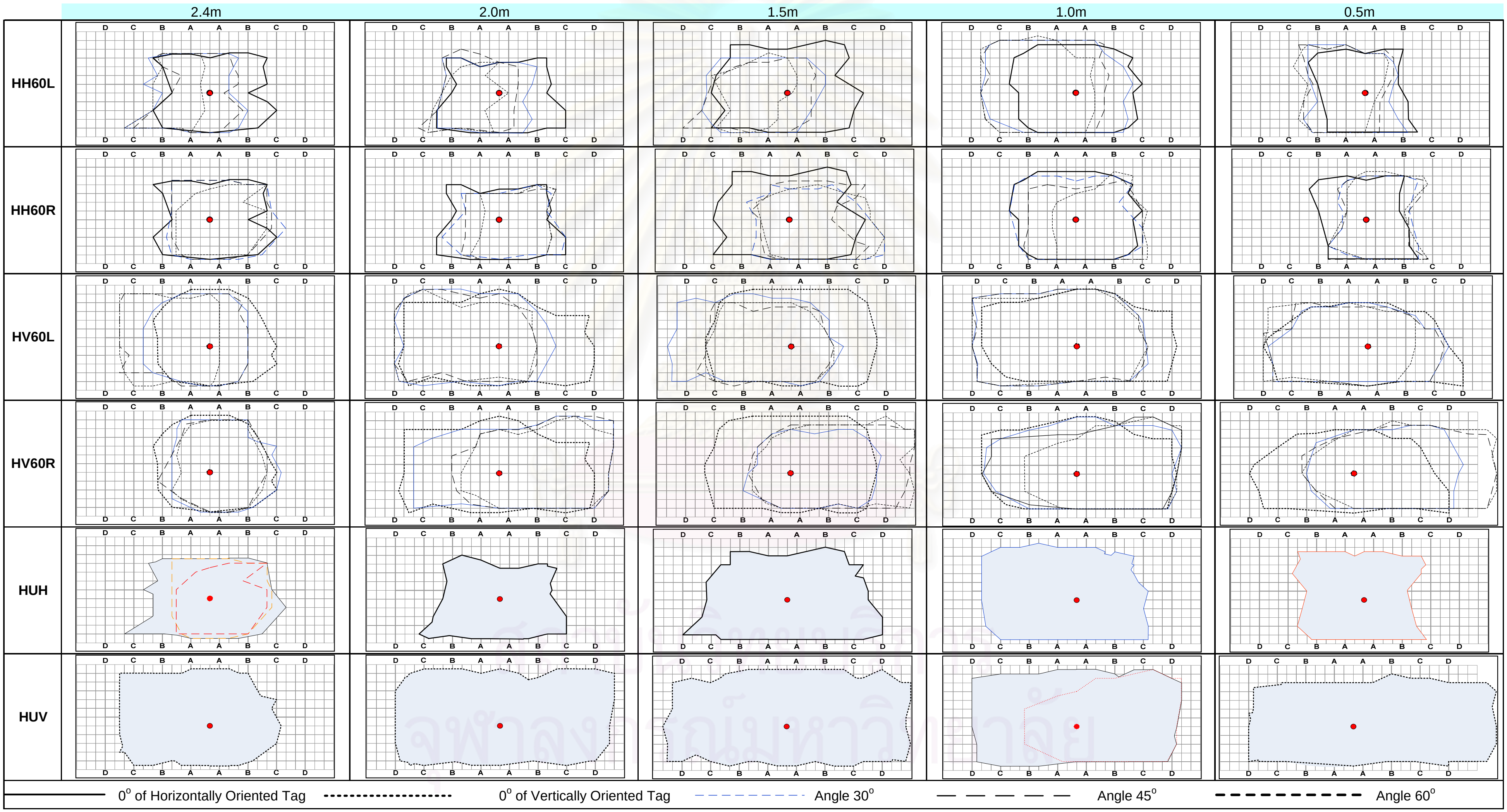


Figure 5.6 At a distance, coverage area were mapped for both horizontal and vertical rotations

5.7.1 Data Collection on Readable Coverage Area

Table 5.2 Readable Coverage Area



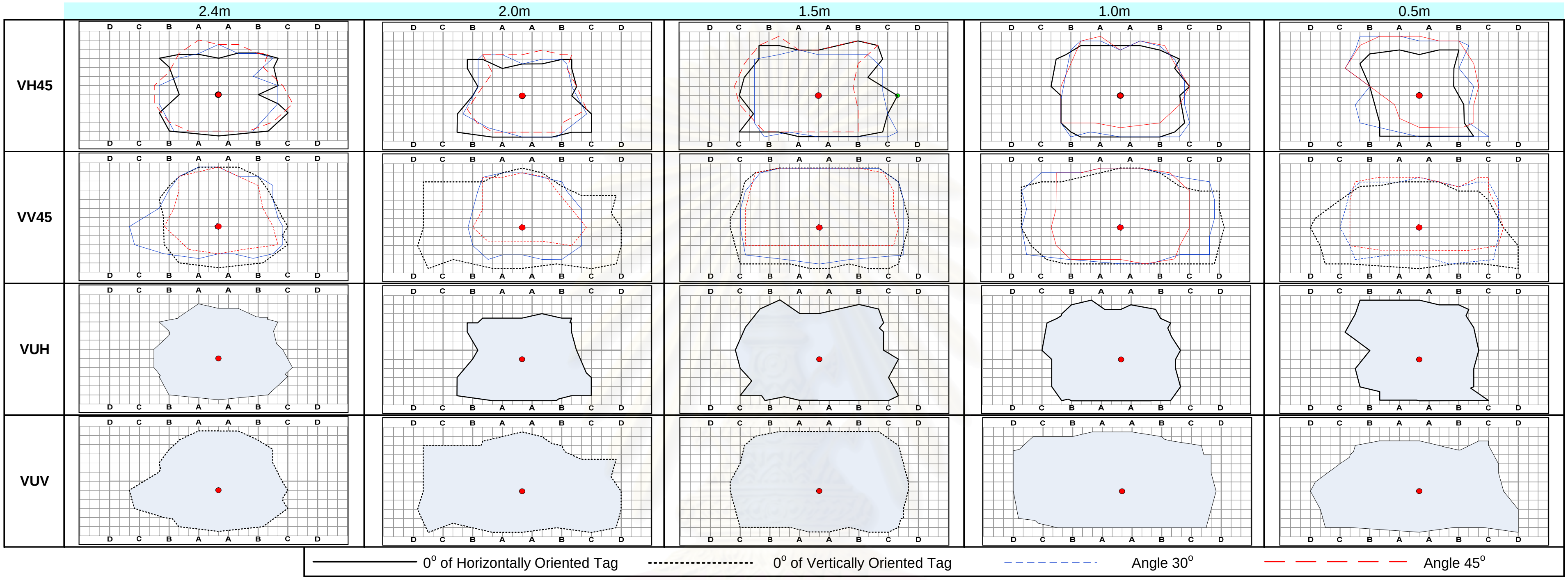


Table 5.3 Description of Notations on Readable Coverage Area

Notations	Description
H - - - -	Reader is horizontally rotated
V - - - -	Reader is vertically rotated
- H - - -	Tag is horizontally oriented Reader is horizontally rotated within associated angles
- V - - -	Tag is vertically oriented Rotation to left direction
- - 60 L/R	Reader is horizontally rotated 60^{o} to the left/ right direction
- - 45	Reader is vertically rotated 45^{o} incline
- U H	Union of mapped coverage area of horizontally oriented tag
- U V	Union of mapped coverage area of vertically oriented tag

5.7.2 Analysis on Readable Coverage Area

Several issues have been observed from the above **Table 5.2** which was the result of investigating the coverage area at various distances, reader rotation angles, and tag orientations. These issues have been classified into two categories based on rotation angles (i.e., horizontal and vertical). The issues are listed in the following sections which are started with horizontally rotated reader in clockwise and counter-clockwise angles then followed by vertically rotated reader in angles 30^{o} and 45^{o} incline.

5.7.2.1 <u>Horizontally Rotated Reader</u>

Horizontally rotated reader has separated its issues based on tag orientations (i.e., horizontal and vertical). The horizontally oriented tag generated several issues as listed below:

- The newly formed area tends to be smaller than previous area when the reader was horizontally rotated both in clockwise and counter-clockwise angles except at distances 0.5 m and 1.0 m.
- Both left and right boundaries of the newly formed area tend to shift in line with the direction of horizontally rotated reader.
- Whenever the left and right most boundaries of resulted area at one distance reached its actual limit, increasing the rotation angle will not make the boundaries of newly formed area exceed those boundaries.
- Lower boundaries were relatively stable whereas the upper boundaries were fluctuating.
- The maximum coverage area which encompasses areas associated with the horizontally rotated reader was reach at the distance 1.0 m then followed by 1.5 m, 2.4 m, 2.0m, and 0.5 m.

Whereas the vertically oriented tag has raised the following issues:

- The formed areas are generally larger than horizontal's both in term of wide and tall.
- Rotating the reader in wider angles will not make the boundaries (i.e., left and right most) of newly formed area exceed a certain resulted boundaries at certain angles which reached its actual limit.
- The boundaries (i.e., left and right most) move in line with the reader's horizontally rotating direction.
- Lower boundaries were relatively stable rather than fluctuated upper boundaries.

- The total coverage area at each distance tends to be larger than previous as the distance decreases from 2.4 m to 1.0 m and become smaller thereafter.

5.7.2.2 __The Vertically Rotated Reader__

The vertically rotated reader has also classified the issues into horizontally and vertically oriented tag. Coincidentally, both horizontally and vertically oriented tag generated the same issues which are as follows:

- As the rotation angle incline upward, the newly formed area tends to be narrower than the previous area.
- The upward rotation of the reader had caused the upper and lower boundaries of newly formed area moved upward.
- Since the newly formed area tends to smaller than previous, the total coverage area is relatively the same as 0^o's coverage area. The horizontally oriented tag reached its maximum total coverage area at distance 1.0 m then followed by 1.5 m, 2.4 m, 2.0m, and 0.5 m. Whereas for the vertically oriented tag, the total coverage tends to be larger than previous as the distance decreases from 2.4 m to 1.0 m and become smaller thereafter.

5.8 The Successful Reading Rate

The followings are the results of investigating the effect of various horizontal clockwise and counter-clockwise angles, distances, and tag orientations to the successful reading rate. There are two parts under the successful reading rate series of tests. The first part compared the successful reading rate under various reading direction (i.e., horizontal angles), distances, and tag orientations whereas the second part compared the successful reading rate between maximum and inner points.

As previously mentioned, 30 times shot were carried out to each of the maximum points which consists of maximum up, down, left, right, upper left, upper right, lower left, and lower right. Each of the maximum points has the number of successful reading out of 30 times shoot. The successful reading rate of a point can be derived by dividing the number of successful reading with 30. A coverage area consists of 7 maximum points. To get the average of the successful reading rate of a coverage area, the successful reading rates of 7 maximum points are added and then divided by the number of maximum points (i.e., 7 points). The overall average of successful reading rate is generated by adding the all the average of successful reading rate of all angles at a distance and then divided by the number of the angles (i.e., 7 angles).

While conducting the test of coverage (readable) area, another 30 times shot were carried out to each of a point that slightly closer to the center from maximum points but only when interrogating at angle 0^o. These new points are perceived as inner points. The inner points generated their own successful reading rate which is derived similarly as the successful reading rate of maximum points. In addition, the inner points also generated an average of successful reading rate. Then the average of successful reading rate of inner points is compared with the average of successful reading rate of maximum points as discussed within section “The Comparison between the Successful Reading Rate at Maximum Point and Inner Points”.

5.8.1 The Successful Reading Rate under Various Conditions

Table 5.4 The results of the successful reading rate under various conditions

		Average Successful Reading Rate of Maximum Points at Angle							
	Tag	Left			0^o	Right			Overall
Distance	Orientation	60^o	45^o	30^o		30^o	45^o	60^o	Average
2.4	Horizontal	78.33	79.58	71.67	75.19	82.92	82.50	80.42	78.66
	Vertical	81.25	80.00	88.75	82.22	82.08	83.33	81.25	82.70
2	Horizontal	82.08	82.50	78.75	78.15	84.58	83.33	82.92	81.76
	Vertical	83.75	84.58	90.00	83.33	83.33	83.75	82.50	84.46
1.5	Horizontal	84.58	82.92	86.67	85.56	89.17	91.67	88.33	86.98
	Vertical	80.00	85.00	87.50	85.56	84.17	83.33	85.83	84.48
1	Horizontal	87.92	87.08	90.42	82.96	90.00	93.33	91.67	89.05
	Vertical	88.75	89.17	91.25	88.89	89.17	89.58	90.00	89.54
0.5	Horizontal	89.17	90.00	90.00	88.52	89.17	92.92	94.17	90.56
	Vertical	88.33	88.33	90.42	91.11	88.33	88.75	89.58	89.27

5.8.1.1 Analysis on The Successful Reading Rate Under Various Conditions

The **Table 5.4** yielded the following figures which describe the characteristics of successful reading rate under the aforementioned conditions. The first and second figures are subject to horizontally and vertically oriented tags respectively. The details discussed in the following sections.

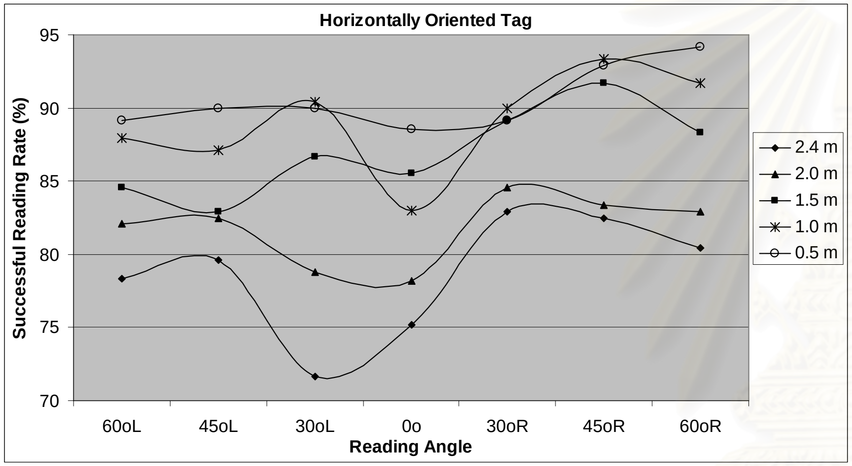


Figure 5.7 The successful reading rate for horizontally oriented tag under various angles and distances

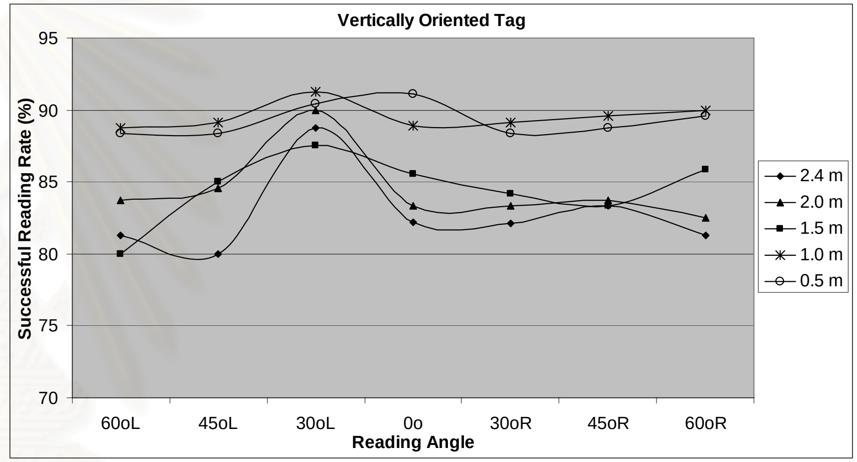


Figure 5.8 The successful reading rate for vertically oriented tag under various angles and distances

As observed from **Figure 5.7**, the horizontally oriented tag has raised several issues about the influence of various angles direction and distances to the successful reading rate. The issues are listed as follows:

- The successful reading rate tends to decrease as the distance increases. It is clearly seen from the graphs, the most below and upper graphs belong to the furthest and the closest distance to the panel respectively.
- As seen from the graphs, the graphs can be clustered at least into two graph patterns. The graphs analysis will be presented based on these patterns and also rotation directions (i.e. left/ counter-clockwise and right/ clockwise).

- The first graph pattern belongs to the two below graphs (i.e., 2.4 m and 2.0 m). Inspecting the left part (i.e., 30^oL, 45^oL, and 60^oL) generated the maximum and the minimum successful reading rates at angle 45^o and 30^o respectively. Whereas the right part (i.e., 30^oR, 45^oR, and 60^oR) reached the maximum and the minimum successful reading rates at angle 30^o and 0^o respectively.
- The second graph pattern belongs to the three upper graphs (i.e., 1.5 m, 1.0 m, and 0.5 m). The left part inspection (i.e., 30^oL, 45^oL, and 60^oL) generated the maximum and the minimum successful reading rates at angle 30^o and 0^o respectively. Whereas the right part (i.e., 30^oR, 45^oR, and 60^oR) reached the maximum and the minimum successful reading rates at angle 45^o and 0^o respectively.

Figure 5.8 is subject to vertically oriented tag. The vertically oriented tag has yielded the following issues around the effect of various angles direction and distances to the successful reading rate:

- The graphs can be clustered at least into three graph patterns. The two most below graphs (i.e., 2.4 m and 2.0 m) which have the same trend are grouped under the same cluster. Whereas the two most upper graphs (i.e., 2.4 m and 2.0 m) are grouped in other cluster. The 1.5 m graph pattern does not match with other clusters thus it stands alone.
- For 2.4 m and 2.0 m, as the distance increases, the successful reading rate tends to decrease. As shown in the graphs, the most below and upper graphs belong to 2.4 m and 2.0 m respectively.
- Opposite than previous cluster. For the 1.0 m and 0.5 m cluster, the successful reading rate tends to increase in line with the distance.
- The graphs reached the maximum successful reading rate at angle 30^o to the left except for distance 0.5 m.

Table 5.5 The overall average of successful reading rate at certain distance

Tag Orientation	The Overall Average of Successful Reading Rate at Distance (m)				
	2.4	2	1.5	1	0.5
Horizontal	78.66	81.76	86.98	89.05	90.56
Vertical	82.70	84.46	84.48	89.54	89.27

The **Table 5.5** above described the trend of successful reading rate under various distances and tag orientations. The overall average of successful reading rate has shown that at any tag orientation, the successful rate tends to incline as the reading distance decreases except for vertically oriented tag at distance 0.5 m. Generally vertically oriented tag has higher successful reading rate compared with horizontal except at distances 1.5 m and 0.5 m.

5.8.2 *The Comparison between the Successful Reading Rate at Maximum Point and Inner Points*

The followings are the results of investigating the effect of the reading at inner points compared with maximum points to the reading successful rate. The expectation is as the reading move closer to the center, the reading successful rate is getting higher.

Table 5.6 The average of successful reading rate at maximum points and inner points

Distance	Tag Orientation	Average of Successful Reading Rate at Angle 0^O Max. Point	A Point Before
2.4	Horizontal	75.19	76.25
	Vertical	82.22	81.67
2	Horizontal	78.15	83.75
	Vertical	83.33	83.75
1.5	Horizontal	85.56	87.50
	Vertical	85.56	87.92
1	Horizontal	82.96	85.00
	Vertical	88.89	90.83
0.5	Horizontal	88.52	89.17
	Vertical	91.11	90.83

5.8.2.1 *Analysis on The Comparison between the Successful Reading Rate at Maximum Point and Inner Points*

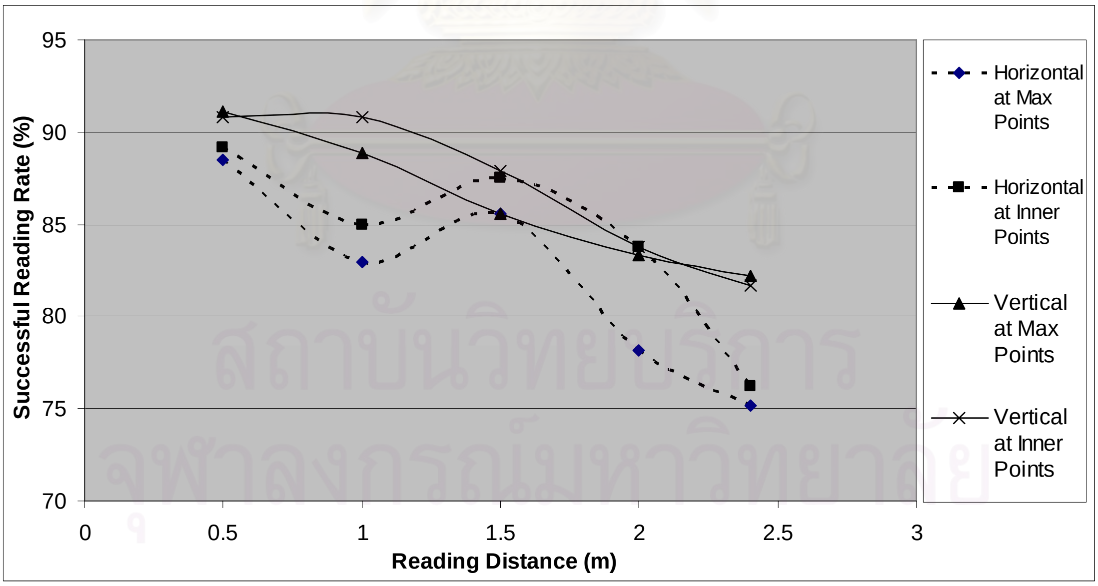


Figure 5.9 The influence of reading at inner points to the reading successful rate

As observed from **Figure 5.9**, several issues have been raised around the effect of reading at inner points to the reading successful rate, as follows:

- As obviously seen in the graphs, given at any conditions, the successful reading rate tends to decrease as the reading distance is moving further.

- As expected, the reading at inner points gives a higher successful reading rate than maximum points.
- The graphs can be clustered into two groups. Horizontal graphs have a very similar graph pattern whereas vertical's have less.
- The successful reading rate of vertically oriented tag is higher than horizontal's.

5.9 Maximum Amount of Detected Tags at Once

This test aims to investigate the limit of detectable number of tags which will respond to one transmitted signal (i.e., 1 time shoot). The signal was transmitted from a certain distances to reach the attached tags on each of three main points which were center, lower, and upper section of coverage area associated with the distance. As described in **Figure 5.10**, for every points at each distance, the tests were conducted both for horizontally and vertically oriented tags to observe the effect of tag orientation.

At first, several even-numbered tags were symmetrically mounted to center line on the wall. Another pair of tags was symmetrically added in the horizontal direction if the reader can still read all the attached tags. As seen in the **Figure 5.10** below, adding tags in the horizontal direction allowed the newly attached pair of tags to be still within the detectable (coverage) area.

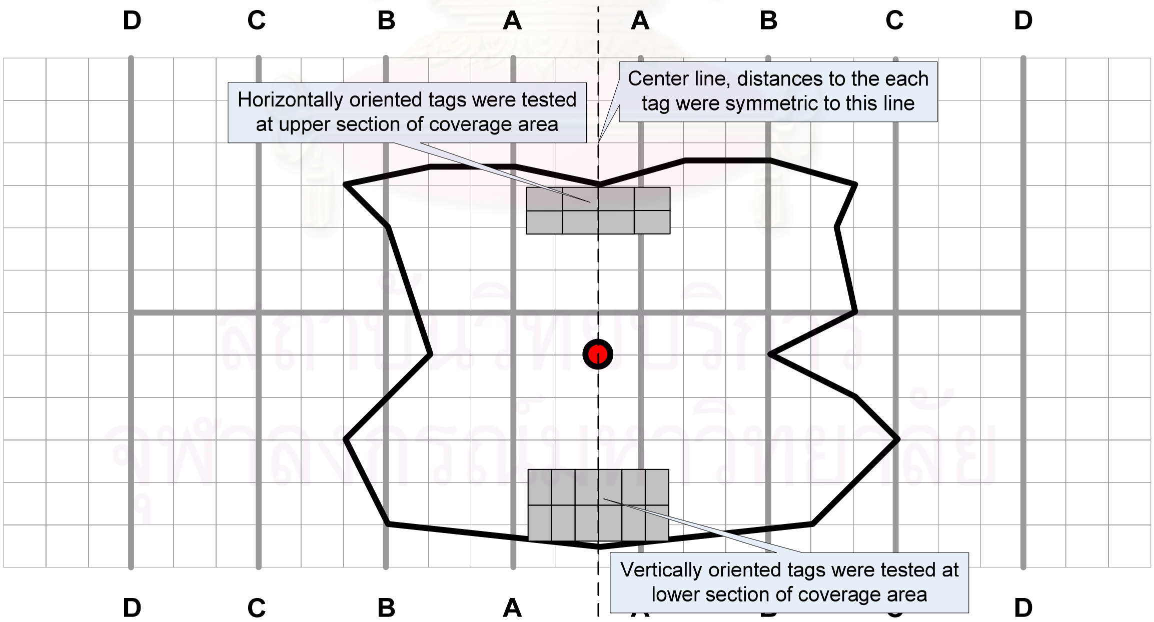


Figure 5.10 At a distance, tags were symmetrically mounted to the center line with regards to tag orientation

The collected data is presented in **Figure 5.11** below.

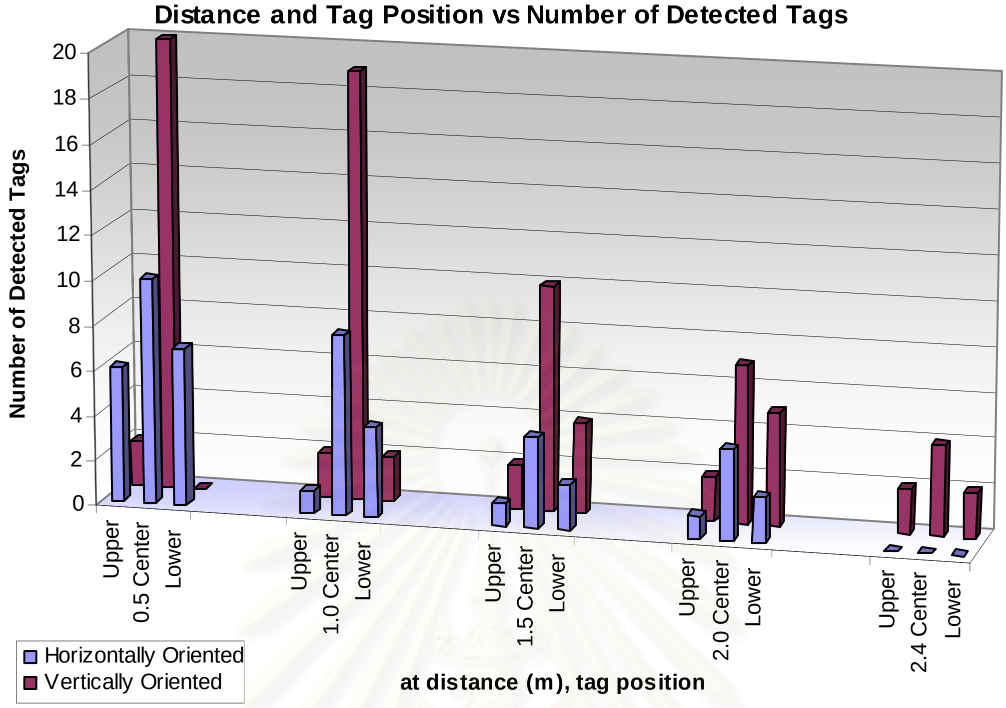


Figure 5.11 The collected data of the maximum amount of detected tags at once

5.9.1 Analysis Maximum Amount of Detected Tags at Once

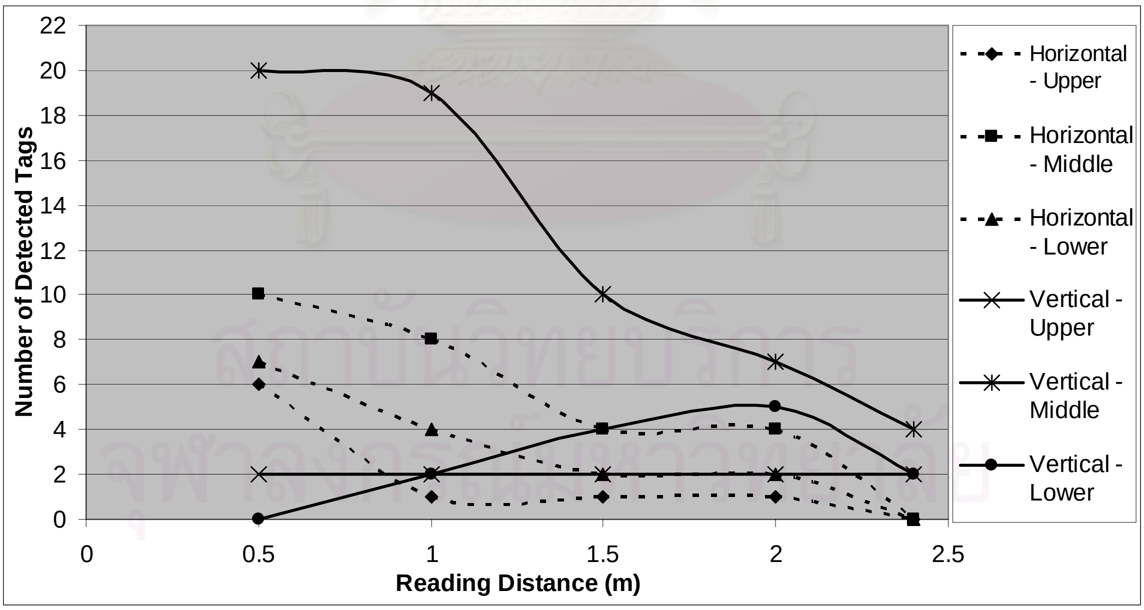


Figure 5.12 The influence of distance, tag position, and tag orientation to the number of detected tags at once

Several issues have been observed from the above **Figure 5.12** which was the result of investigating the number of detected tags at once at various distances, tag positions, and tag orientations. These issues have been classified into two categories based on tag orientations (i.e., horizontal and vertical). The issues are listed in the following sections starting with the horizontally oriented tags followed by vertically oriented tags and lastly comparisons between these two tag orientations.

Horizontally oriented tags yielded three issues as follows:

- As the reading distance increases, the number of detected tags at once tends to decrease.
- Center tag placement generates the maximum number of detected tags at once followed by lower and upper positions, consecutively.
- At distance 1.5 m and 2 m, all positions give a constant value for the number of detected tags at once.

Whereas the vertically oriented tags have the following issues:

- Center position tends to score a lower number of detected tags as the reading distance increase.
- Upper position gives a constant number of detected tags at once at any distances.
- The number of detected tags at once tends to rise in line with the distance and reach the maximum at distance 2 m and decrease thereafter.

The comparison between two tag orientations has the issues as follows:

- Generally, vertically oriented tags yield a higher number of detected tags at once than horizontal except at distance 0.5 m and 1 m.
- At distance 0.5 m, horizontally oriented tags score a higher number of detected tags than vertical particularly at upper and lower positions. The same thing happened at distance 1 m though it only occurs at lower position.

5.10 Minimum Distance (Spacing) between Tags to be Read Separately

This section aims to obtain the minimum spacing distance between tags that can still be read separately. The behavior of placing two adjacent tags was also investigated within this section. Similarly with the previous section, the signal was transmitted to reach the mounted tags on each of those three points. Again, the effects of tag orientations were investigated by conducting the test for both orientations.

As shown in the **Figure 5.13**, in the beginning, two identically oriented tags were separately placed on the wall at certain distance symmetrical to center line. The separating distance was symmetrically enlarged whenever the portable reader's reading yielded two tags at once. The increase in distance was directed to the horizontal direction to ensure that the current tag position was still within coverage area.

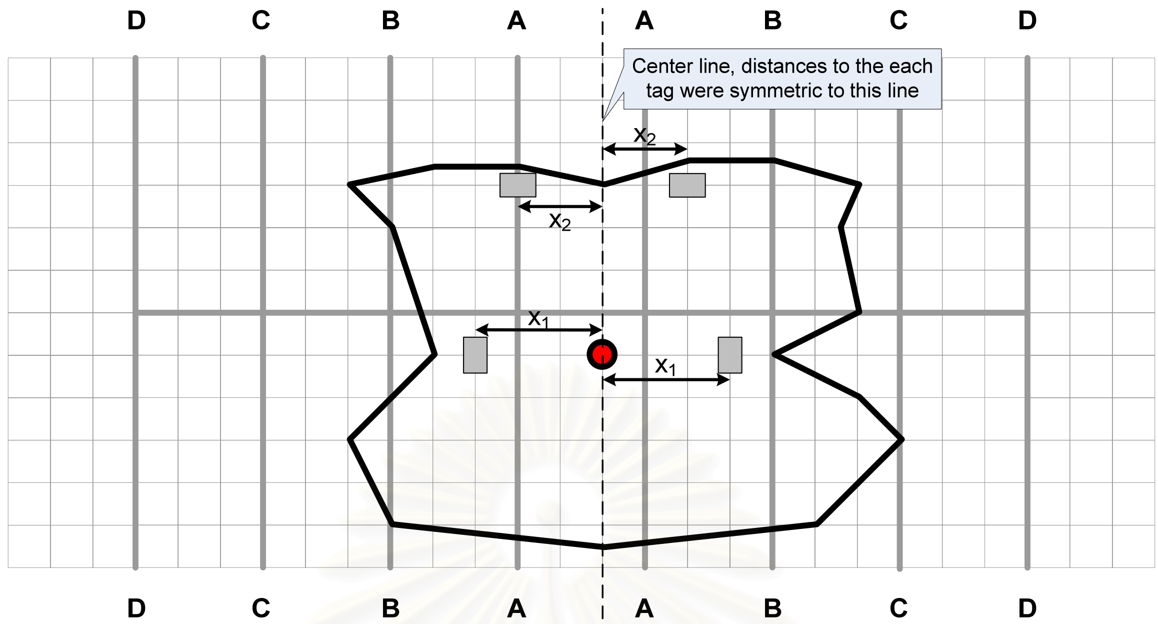


Figure 5.13 At a distance, two adjacent tags were separately placed within symmetrical distance to center line

The collected data is presented in **Figure 5.14** below.

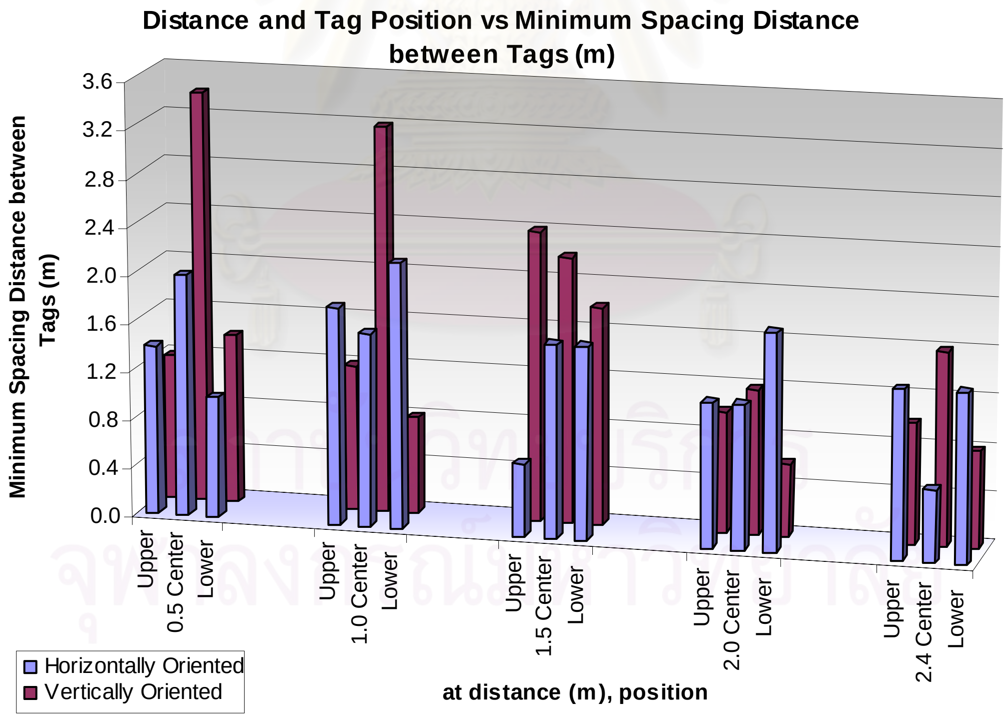


Figure 5.14 The collected data of the minimum distance (spacing) between tags to be read separately

5.10.1 Analysis Minimum Distance (Spacing) between Tags to be Read Separately

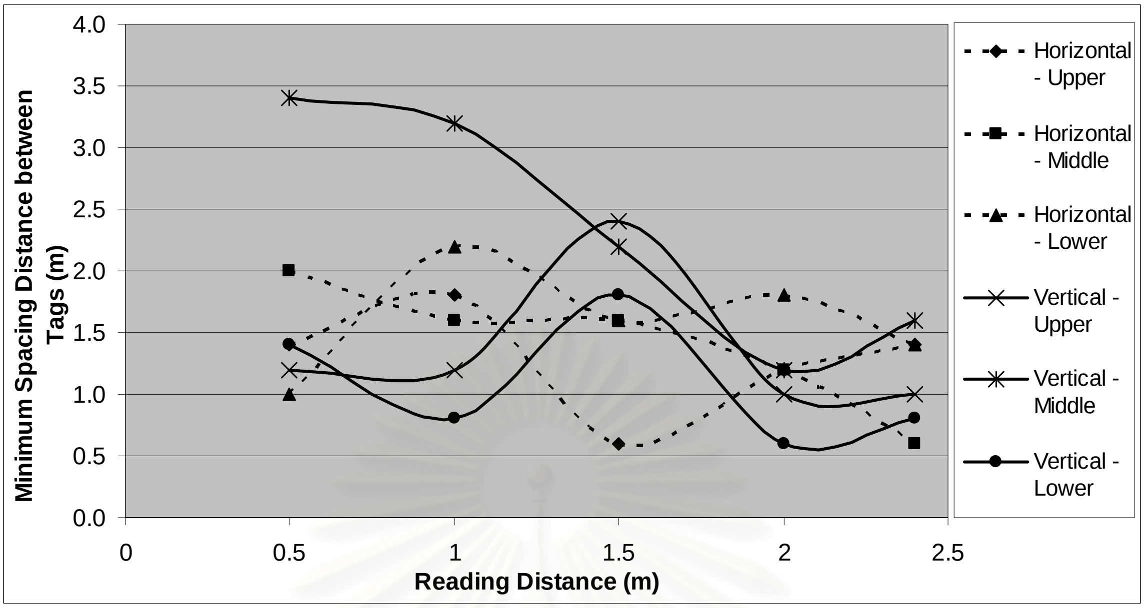


Figure 5.15 The effect of distance, tag positions, and tag orientations to the minimum spacing distance between tags

Generated from the investigation of minimum spacing distance between tags, **Figure 5.15** presents the influence of distance, tag positions, and tag orientations to the investigation. The influence is perceived as issues which are classified into two categories based on tag orientations. The following sections listed the issues; starting with the horizontally oriented tag followed by the vertical and the comparisons, consecutively.

The issues related to the horizontally oriented tags are as follows:

- Center position tends to have a narrower spacing distance between tags as the reading distance increase.
- Upper and lower positions generate the same trend which has maximum and minimum points; both reach the peak points at distance 1 m.
- Compared with upper, lower position yields a wider spacing distance between tags though started with a narrower spacing distance.

The vertically oriented tags have raised the following issues:

- At center position, further reading distance generates narrower spacing distance between tags.
- Both upper and lower positions have the same trend which has peak and valley points. Both reach peak and valley points at distance 1.5 m and 2 m respectively.
- Upper position generates a wider spacing distance between tags than lower position though started with a narrower spacing distance.

The comparison between two tag orientations generates several issues as follows:

- Both upper positions of horizontally and vertically oriented tags reach their peak and valley points respectively at distance 1.5 m.
- Horizontally and vertically oriented tags generate graph that is in contrast with one to another.
- For center position, both horizontally and vertically oriented tags yield the same trend.
- At lower and upper positions of horizontally and vertically oriented tags, the curve tends to have wider spacing distance whenever it started with a narrower spacing distance.

5.11 Simulation of Placing 1 Precast Panel on A-frame

This test aims to obtain the basic behavior when the tag was mounted on simulated precast panel as seen in the **Figure 5.16**. A Styrofoam was placed perpendicular to the wall to simulate the actual precast panel placement in A-frame. The tag was then placed on the simulated precast panel within three spots which were upper, middle, and lower. The tag positions were also subjected to tag orientations.

As illustrated in **Figure 5.16**, for every spot, signals were transmitted in three directions which consist of the side, 45^{o}, and front readings. The maximum reading distances associated with the three directions were measured. The yielded measurement and analyzed behavior were being concerned in performing the simulation of placing two precast panels in A-frame.

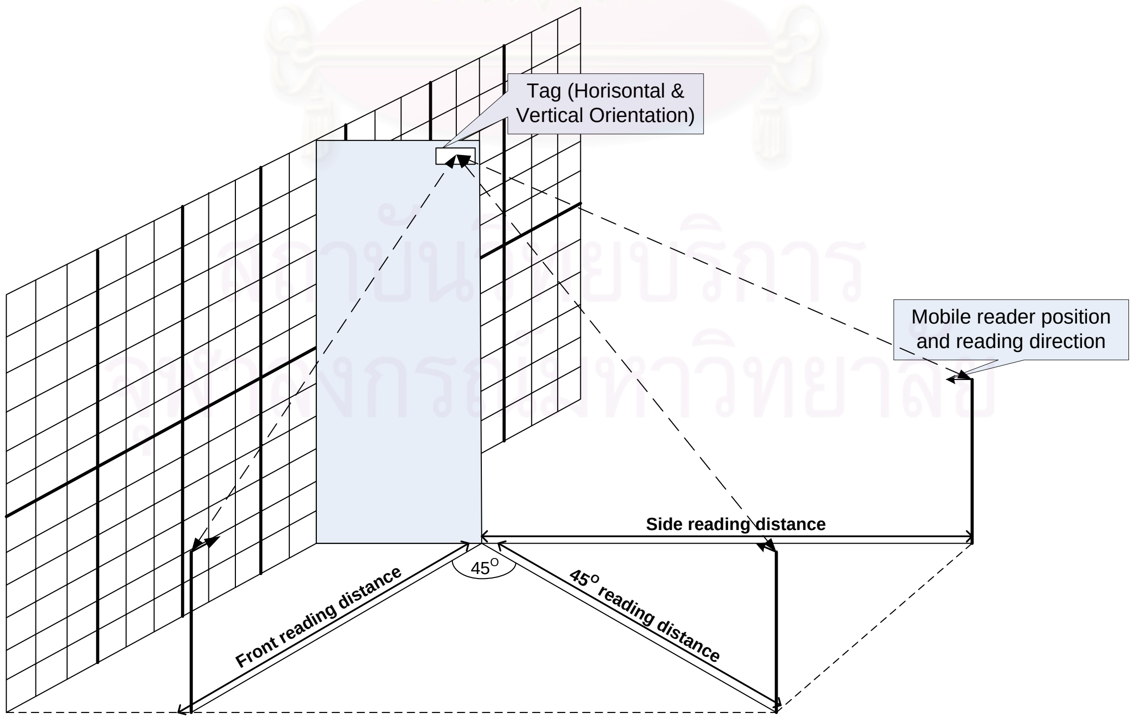


Figure 5.16 Tag position and tag orientations on the simulated precast panel were investigated from three directions

The collected data is presented in **Figure 5.17** below.

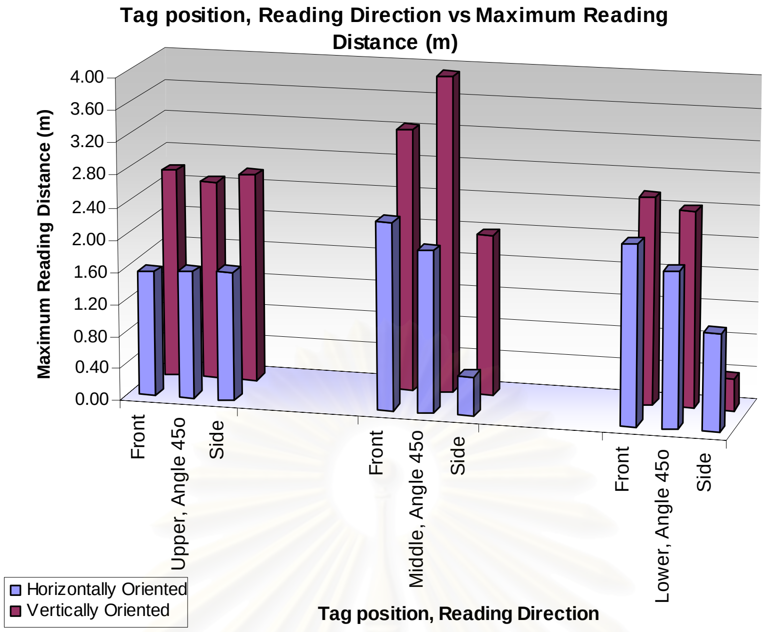


Figure 5.17 The collected data of the simulation of placing 1 precast panel on A-frame

5.11.1 Analysis Simulation of Placing 1 Precast Panel on A-frame

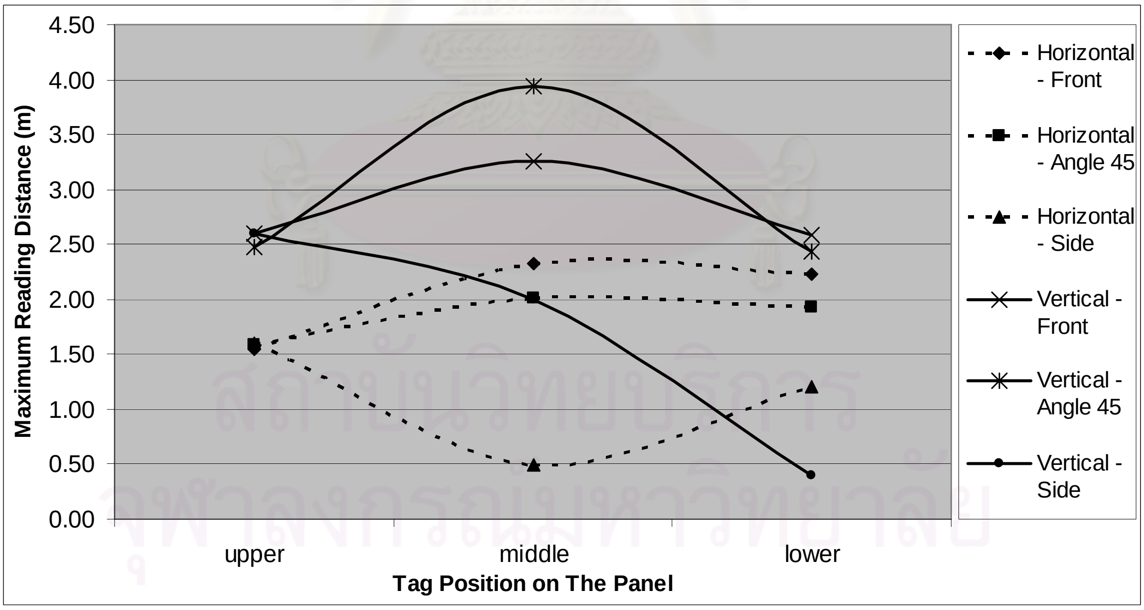


Figure 5.18 The effect of reading directions, tag positions, and tag orientations to the maximum reading distance

Figure 5.18 presents the effect of interrogating tag which placed on various positions within different tag orientations from various reading directions to the

maximum reading distance. In this regards, several issues have been raised and issues are grouped based on tag orientations. The issues are listed in the following section.
Horizontally oriented tags have the following issues:

- Both front and angle 45^o reading directions have the same trend. The maximum reading distance increases and reaches the peak as the tag moved from upper to middle position and decrease thereafter.
- In contrast with front and angle 45^o, side reading direction decreases maximum reading distance and reaches the valley as the tag is moved from the upper to the middle position and increase thereafter.
- All reading directions generate relatively the same maximum reading distance at upper position.
- Front reading direction yields the furthest reading distance than any other reading directions.

Vertically oriented tags have the following issues:

- Front and angle 45^o reading directions generate the same trend where both increases and reach the maximum reading distance at middle position and decrease thereafter.
- Side reading tends to decrease the maximum reading distance as the tag position move downwards.
- All reading directions yield relatively the same maximum reading distance at upper position.
- Front reading direction generates the furthest reading distance than any other reading directions.

Comparisons between two tag orientations have the following observations:

- Generally, vertically oriented tags yield further reading distance than horizontal ones.
- At middle position, all reading directions reach their extreme points where both front and 45^o reach the maximum reading distance.
- At upper position, all reading directions generate a relatively the same maximum reading distance associated to with its tag orientation.
- Front reading distance generates a higher maximum reading distance than any other reading directions.

5.12 Simulation of Placing 2 Precast Panels in A-frame

These series of tests aim to investigate the behavior of tags which were mounted on two adjacent simulated and separately placed precast panels at certain distances. There were two groups of tests within this section. First group was addressed to investigate the effect of the distance (spacing) between panels to the 45^o reading distance. The second was directed to investigate the effect of combinations between tag positions and tag orientations to the 45^{o} and side reading distances given a fixed spacing between panels.

First group was performed by measuring 45^{o} reading distance given certain distances between panels which were 0.2 m, 0.4 m, and 0.6 m. Another measurement was performed along the projection line of the maximum reading distance of associated distance between panels to the center line.

Second group was conducted under different combinations between tag positions on panel and tag orientations given a fixed spacing between panels (i.e., 0.2 m as current practice of placing precast panels in A-frame). Reading distances from certain directions (i.e., 45^{o} reading, side reading of 1st panel and side reading of 2nd panel) were measured.

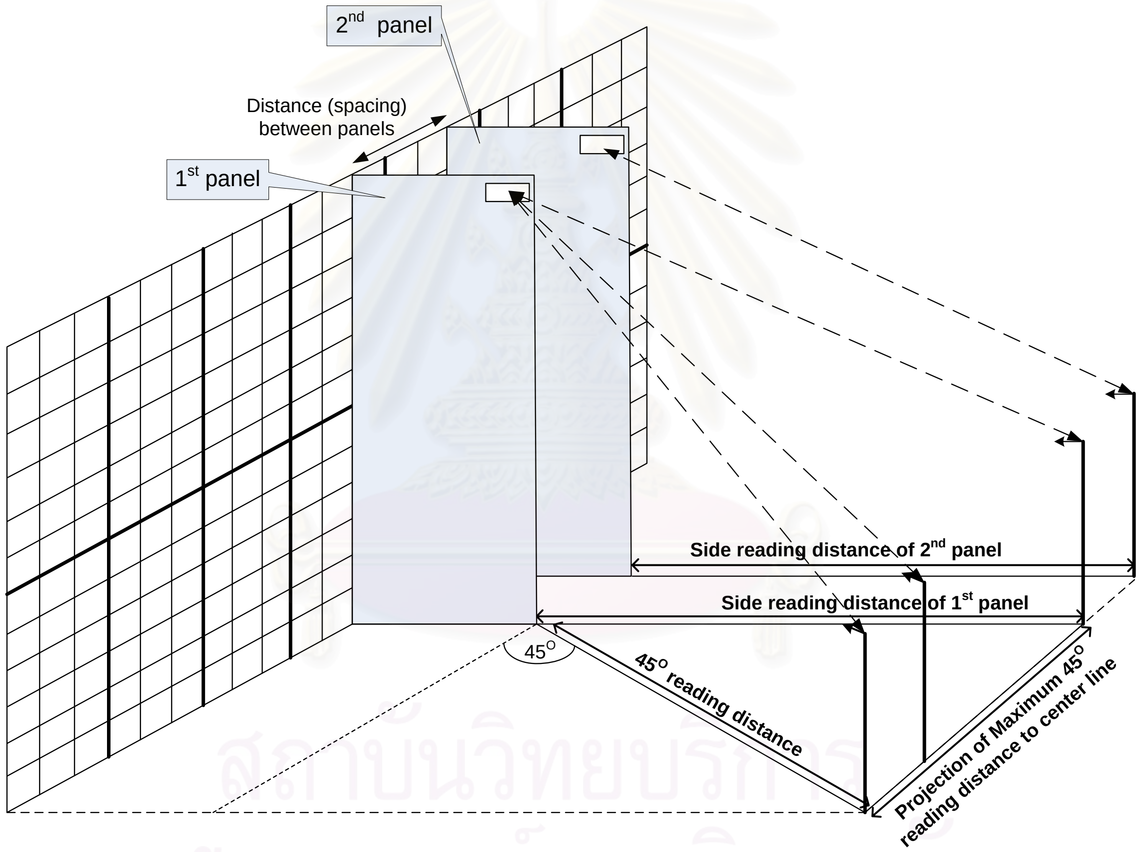


Figure 5.19 Simulation of placing two adjacent precast panels

5.12.1 Measurement of 45^o reading distance

Table 5.7 The collected data of the measurement of 45^o reading distance

	Spacing distance between panels (m)	reading distance (m)	Detected panel	Maximum Reading Distance
45^o reading	0.2	1.81	1st	maximum distance is 2.48 m as generated from the Simulation of Placing 1 Prefab Panel on A-frame
		1.79	both	
	0.4	2.23	1st	
		2.20	both	
	0.6	2.86	1st	reading distance exceeds 2.48 m, then the new maximum distance is 2.86 m
		2.76	both	
Projection of Maximum 45^o reading to center line	0.2	1.31	1st	maximum distance at 2.48 m is 1.74 m from center line
		1.29	both	
	0.4	1.52	1st	
		1.50	both	
	0.6	1.48	1st	maximum distance at 2.86 m is 2.01 m from center line
		1.47	both	

5.12.1.1 <u>Analysis on the Measurement of 45^o reading distance</u>

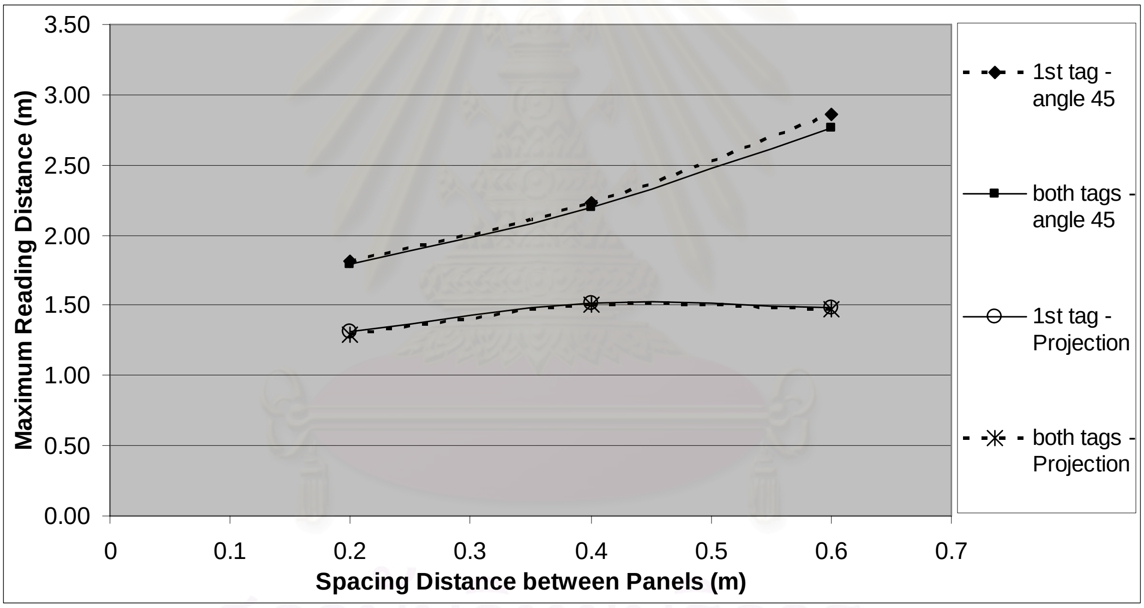


Figure 5.20 The influence of spacing distance between panels to the reading distance of 45^o reading direction

As generated from the previous series of tests, the front reading direction yields a higher maximum reading distance than 45^o reading direction. Whereas side reading direction has relatively less maximum reading distance than others. These results are important concerns to be able to comply with the current practice of prefabrication installation process.

In the current practice, the panels are arranged in parallel manner on A-Frame, thus it is impractical to utilize the front reading direction in interrogating the mounted tag on the panels though it yields the highest maximum reading range. Therefore the other two reading directions (i.e., 45^o and side) are considered as suitable method in interrogating the mounted tag on the panels. These two reading directions allow a higher mobility in interrogating the tags by walking along the side of the panels at a certain distances.

As previously mentioned, this series of tests aims to propose the proper usage of RFID system in interrogating tag individually. It means whenever the portable reader interrogates a particular tag, only the interrogated tag will respond to the reader. Therefore it is essential to find a suitable reading technique to avoid interference from other tags while interrogating a particular tag.

The 45^o reading direction yields a higher maximum reading distance than side's, thus 45^o reading direction has higher possibility to experience interference from other tags which are particularly mounted at the same level. In this regard, adjusting the spacing between panels as one of the techniques was investigated to overcome the interference from other tags. Instead of investigating the 45^o reading distance, the tests were also conducted to examine the effect of interrogating under the same angle along the projection of maximum 45^o reading direction to the center line (as shown in Figure 4.10).

The effect of spacing distance between panels to the reading distance of 45^o reading direction is presented in the **Figure 5.20**. Several raised issues have been raised and classified based on two measurements which are the measurement on 45^o reading direction and along the projection line of maximum 45^o reading distance to the center line. The issues are listed in the following section.

The measurements on 45^o reading direction have the following issues:

- The detection of first panel and both panels have the same trend. As the spacing distance between panel increases, the reading distance on 45^o reading direction also increases.
- Further distance within the reading range on 45^o reading direction of the 1st panel limits the reading only to the 1st or without experiencing interference of 2nd panel.

Measurements on the projection line of maximum 45^o reading distance to the center line have the following issues:

- The same trend occurs to the detection of first panel and both panels. Although the graph is visually (as seen in the **Figure 5.20**) shows a decrease after reaching the peak at a distance of 0.4 m, the direct distance increases thereafter. Note that the last measurement was made on the new projection line of maximum 45^o reading distance, not the same line as two previous measurements. Given the spacing distance between panels is at 0.6 m, the reading distance on 45^o reading direction increased to 2.68 m. The length of the new projection from this point is about 2.01 m whereas the previous length is only 1.74 m. With regards to the aforementioned facts, the reading distance on the projection line increases as the spacing distance between panel increases.

- Selective reading only to the 1st panel can be gained when the measurement was performed at further distance within the reading range at 45° reading direction of 1st panel.

5.12.2 Reading Distance from various directions under different combinations between tag positions on panel and tag orientations

Table 5.8 Eight considered combinations between tag positions on panel and tag orientations

	1st Tag				2nd Tag			
	Vertically Oriented		Horizontally Oriented		Vertically Oriented		Horizontally Oriented	
Combinations	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
1	✓				✓			
2	✓					✓		
3	✓						✓	
4	✓							✓
5			✓				✓	
6			✓					✓
7			✓		✓			
8			✓			✓		

Table 5.9 The collected data of the combinations between tag positions on panel and tag orientations (1st Combination)

Tags Position		Reading from the 1st Panel Side				Reading from the 2nd Panel Side			
1st Tag position	2nd Tag position	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks
Vertical/Upper Side 2.6m Angle 45 2.48	Vertical/Upper Side 2.6m Angle 45 2.48	Side	1st panel	2.94		Side	2nd panel	2.94	
			2nd panel	2.82	both		1st panel	2.82	both
The numbers above are generated from the Simulation of Placing 1 Prefab Panel on A-frame		Angle 45°	1st panel	1.31		Angle 45°	2nd panel	are not tested	
			2nd panel	1.29	both		1st panel		

Two vertically oriented tags were mounted on two adjacent panels at the upper position have a longer distance of side reading direction compared to interrogating the individual ones. The longest distance in interrogating side reading both from 1st and 2nd panels allows only the associated panel to give response. Slightly closer reading of each panel results in the detection of both panels, i.e., the 2nd panel was detected. This distance is even longer than 45° reading's distance of the 2nd panel. The same thing occurred when the 2nd panel was interrogated. Opposite from side reading results; the resulted reading distances of 45° reading direction are much shorter than individual ones.

Table 5.9 The collected data of the combinations between tag positions on panel and tag orientations (2nd Combination)

Tags Position		Reading from the 1st Panel Side				Reading from the 2nd Panel Side			
1st Tag position	2nd Tag position	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks
Vertical/Upper Side 2.6m Angle 45 2.48	Vertical/Lower Side 0.4 Angle 45 2.44	Side	1st panel	2.94	sometimes 1st, sometimes 2nd	Side	2nd panel	2.29	both, tends to 1st
			2nd panel	2.82	tends to read 2nd		1st panel	2.6	
The numbers above are generated from the Simulation of Placing 1 Prefab Panel on A-frame		Angle 45^o	1st panel	2.3		Angle 45^o	2nd panel	are not tested	
			2nd panel	2.27	both		1st panel		

The vertically oriented tags were placed on the 1st and 2nd panels at upper and lower positions, respectively. Placing the vertically oriented tag at a lower position significantly reduced the reading distance of side reading direction. Interrogating the longer side reading distance from 1st panel yielded the alternatively detection of 1st and 2nd panels. Whenever the reader moved slightly closer to the panel, both panels were detected. Both of these results of side reading were longer than individual ones. The side reading from 2nd panel generated mostly the detection of 1st panel whereas the 2nd panel was rare and detected at moderately closer distance to the panel. This distance was significantly further than individual ones.

For the 45^o reading, since both tags yield a relatively the same 45^o reading distance, the results were expected to be not much different than individual readings. The results of 45^o reading were moderately shorter than individual ones. Slightly closer distance to the panel allowed the detection of the 2nd panel instead of the 1st panel.

Table 5.9 The collected data of the combinations between tag positions on panel and tag orientations (3rd Combination)

Tags Position		Reading from the 1st Panel Side				Reading from the 2nd Panel Side			
1st Tag position	2nd Tag position	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks
Vertical/Upper Side 2.6m Angle 45 2.48	Horisontal/Upper Side 1.6 Angle 45 1.58	Side	1st panel	2.6		Side	2nd panel	<=1.6	both
			2nd panel	1.6	both		1st panel	> 1.6	
The numbers above are generated from the Simulation of Placing 1 Prefab Panel on A-frame		Angle 45^o	1st panel	2.4		Angle 45^o	2nd panel	are not tested	
			2nd panel	2.38	both		1st panel		

Two tags were placed differently on two adjacent panels. The vertically and horizontally oriented tags were mounted at the upper position on the 1st and 2nd panels respectively. Obviously though the 2nd tag was placed at the same position, since it is horizontally oriented, the reading distances for both reading direction were much shorter than vertical ones. The side reading from the 1st panel reached the same distance as the individual ones. The 2nd panel was detected at a much closer distance to the panel instead of detecting the 1st panel and this distance was relatively the same with the individual ones. Whereas from the side reading of the 2nd panel, it generate relatively the same distance with individual readings though it detected the both panels. The 1^{st} panel was detected individually at a further distance.

The 45^o reading generated almost the same distance as the 1^{st}'s to detect only the 1^{st} panel whereas both panels were detected at a slightly closer distance to the panel. This distance is moderately greater than the individual reading of the 2^{nd} panel.

Table 5.9 The collected data of the combinations between tag positions on panel and tag orientations (4^{th} Combination)

Tags Position		Reading from the 1st Panel Side				Reading from the 2nd Panel Side			
1st Tag position	2nd Tag position	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks
Vertical/Upper	Horisontal/Lower	Side	1st panel	2.6		Side	2nd panel	<=1.4	both
Side 2.6m	Side 1.2								
Angle 45 2.48	Angle 45 1.93		2nd panel	1.2	rarely read 1st, never both		1st panel	>1.4	
The numbers above are generated from the Simulation of Placing 1 Prefab Panel on A-frame		Angle 45^o	1st panel	2.6		Angle 45^o	2nd panel	are not tested	
			2nd panel	1.92	both		1st panel		

The vertically oriented tag on the 1^{st} panel and the horizontally oriented tag on 2^{nd} panel were attached at the upper and lower position respectively. The results of side reading were the same with previous result. But for the 45^o reading distance, reading distance is slightly further distance than 1^{st}'s and detected the 2^{nd} panel at a relatively same distance with 2^{nd}'s instead of 1^{st} panel.

Table 5.9 The collected data of the combinations between tag positions on panel and tag orientations (5^{th} Combination)

Tags Position		Reading from the 1st Panel Side				Reading from the 2nd Panel Side			
1st Tag position	2nd Tag position	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks
Horisontal/Upper	Horisontal/Upper	Side	1st panel	1.6		Side	2nd panel	<1.2	
Side 1.6	Side 1.6								
Angle 45 1.58	Angle 45 1.58		2nd panel	1.25/ 1.1	both/ 2nd		1st panel	1.25-1.4/ >1.4	both/ 1st
The numbers above are generated from the Simulation of Placing 1 Prefab Panel on A-frame		Angle 45^o	1st panel	<=1.63	both	Angle 45^o	2nd panel	are not tested	
			2nd panel	>1.63 , 1.9			1st panel		

Two horizontally oriented tags were placed at upper position on two adjacent panels. Thus the tags have the same properties for both reading directions. The side reading from 1^{st} panel yielded the same distance as 1^{st}'s. Whereas the reading distance for detecting both and only the 2^{nd} panel were moderately shorter than the 2^{nd}'s. The side reading from the 2^{nd} panel generated unexpected result though both tags have the same properties. The side reading was dominated by the detection of the 1^{st} panel at a slightly shorter distance than the 1^{st}'s then followed by both panels. The 2^{nd} panel was detected individually at moderately shorter distance as the 2^{nd}'s.

The 45^o reading had been dominated by the 2^{nd} panel even though 2^{nd} panel has the same reading distance as 1^{st}'s. The distances were relatively the same as individual ones. Slightly shorter reading distance allowed the detection of 1^{st} panel instead of the 2^{nd} and the distance was the same as the 1^{st}'s.

Table 5.9 The collected data of the combinations between tag positions on panel and tag orientations (6^{th} Combination)

Tags Position		Reading from the 1st Panel Side				Reading from the 2nd Panel Side			
1st Tag position	2nd Tag position	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks
Horisontal/Upper	Horisontal/Lower	Side	1st panel	>1.7		Side	2nd panel	1.7	tends to 2nd
Side 1.6	Side 1.2		2nd panel	1.6	both		1st panel	1.6	both
Angle 45 1.58	Angle 45 1.93	Angle 45^{o}	1st panel	2.6		Angle 45^{o}	2nd panel	are not tested	
The numbers above are generated from the Simulation of Placing 1 Prefab Panel on A-frame			2nd panel	1.58/ > 1.58 - 2.39	both/ both tends to 2nd		1st panel		

Two horizontally oriented tags were attached on the 1^{st} and 2^{nd} panel at the upper and lower positions respectively. From the result of this tags placement combination, the tags performed individually with less interference from each other. This tags placement was considered as the suitable placement later on.

The side reading from the 1^{st} panel generated a slightly further distance than the 1^{st}'s to detect only the 1^{st} panel. The 2^{nd} panel was detected instead of the 1^{st} at a slightly closer distance though this distance was moderately further than 2^{nd}'s. Whereas from the 2^{nd} panel's side, the furthest distance was reached to detect only the 2^{nd} panel and this distance was moderately further than 2^{nd}'s. Slightly shorter distance allowed the detection of the 1^{st} panel instead of the 2^{nd}.

The 45^{o} reading generated a significantly further distance than the 45^{o} reading distance of the 1^{st} and 2^{nd} panels. The furthest reading distance allowed the detection only to the 1^{st} panel and moderately shorter distance detected both panels with a tendency to read the 2^{nd} panel more frequent.

Table 5.9 The collected data of the combinations between tag positions on panel and tag orientations (7^{th} Combination)

Tags Position		Reading from the 1st Panel Side				Reading from the 2nd Panel Side			
1st Tag position	2nd Tag position	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks
Horisontal/Upper	Vertical/Upper	Side	1st panel	1.63/ 0.85	both/ 1st	Side	2nd panel	2.6	
Side 1.6	Side 2.6m		2nd panel	2.27			1st panel	1.75	both
Angle 45 1.58	Angle 45 2.48	Angle 45^{o}	1st panel	2.1	both	Angle 45^{o}	2nd panel	are not tested	
The numbers above are generated from the Simulation of Placing 1 Prefab Panel on A-frame			2nd panel	2.36			1st panel		

Horizontally and vertically oriented tags were mounted on the 1^{st} and 2^{nd} panel respectively at the upper position. The 2^{nd} panel has better performance in both reading directions. Thus it was predicted that the reading results will be dominated by the 2^{nd} panel.

The side reading results has shown the domination of the 2nd panel in all reading distances. For instance, side reading from the 1st panel shows that the 2nd panel was detected at maximum reading distance and this distance was moderately shorter than 2nd's. Whereas the detection of the 1st panel itself, instead of 2nd, occurred at almost the same distance as 1st's.

From the 2nd panel, the side reading detected only the 2nd panel at the same distance as the 2nd's whereas the 1st panel was detected instead of the 2nd at a slightly further distance than the 1st's.

Obviously for the 45° reading, the strongest will dominate the reading distance. The results had shown that the 2nd panel was detected individually at the furthest distance which was slightly further than the 2nd's. Instead of the 2nd panel, the 1st panel was detected at a moderately further distance than the 1st's.

Table 5.9 The collected data of the combinations between tag positions on panel and tag orientations (8th Combination)

Tags Position		Reading from the 1st Panel Side				Reading from the 2nd Panel Side			
1st Tag position	2nd Tag position	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks	Reading Direction	The Detection of	At Distance (from panels) (m)	Remarks
Horisontal/Upper	Vertical/Lower	Side	1st panel	1.6	both	Side	2nd panel	0.4	both
Side 1.6	Side 0.4								
Angle 45 1.58	Angle 45 2.44		2nd panel	<2.44			1st panel	at any distance	
The numbers above are generated from the Simulation of Placing 1 Prefab Panel on A-frame		Angle 45°	1st panel	2.2	both	Angle 45°	2nd panel	are not tested	
			2nd panel	>2.3	2nd		1st panel		

The horizontally oriented tag on the 1st panel and vertically oriented tag on the 2nd panel were attached at upper and lower position respectively. The Vertically oriented tag has better performance particularly at 45° reading direction whereas the side reading distance is only at less than a half meter. These unbalanced properties have strong influence to the others when interrogating from other side but it hinders the detection when interrogating from its side.

The side reading from the 1st panel was dominated by the detection of the 2nd panel at the same distance as 2nd's 45° reading direction. The 1st panel was detected instead of the 2nd panel at the same distance as the 1st's. But from the side of the 2nd panel, the reading was dominated by the 1st panel and at the same distance as the 1st's. Instead of the 1st panel, the 2nd panel was detected at the same distance as the 2nd's. The 45° reading shows the same pattern with the previous result of 45° reading.

5.13 Simulation of Placing 3 Precast Panels on A-frame

This last test aims to obtain best combinations of tag placement and determine the best usage of portable reader by simulating 3 adjacent precast panels in A-frame. As shown in the **Figure 5.21**, three panels were placed perpendicular to the wall and separated at equal distances 0.2 m as reflecting the current practice of panels' placement. The best combination of tag orientation and tag placement was selected that will result in only one tag being detected once the reader interrogates a particular panel.

According to previous result (simulation of placing 2 precast panels in A-frame), the suggested usage of tag orientation was horizontal. Due to the limited reading distance that yielded from horizontally oriented tag, at certain distance the tags will not interfere with each other (means the reader will only detect one tag at once). Consequently the reading distance will not be as far as the vertically oriented ones. This selection of horizontally oriented tag had narrowed the number of possible combinations between tag orientations and tag positions.

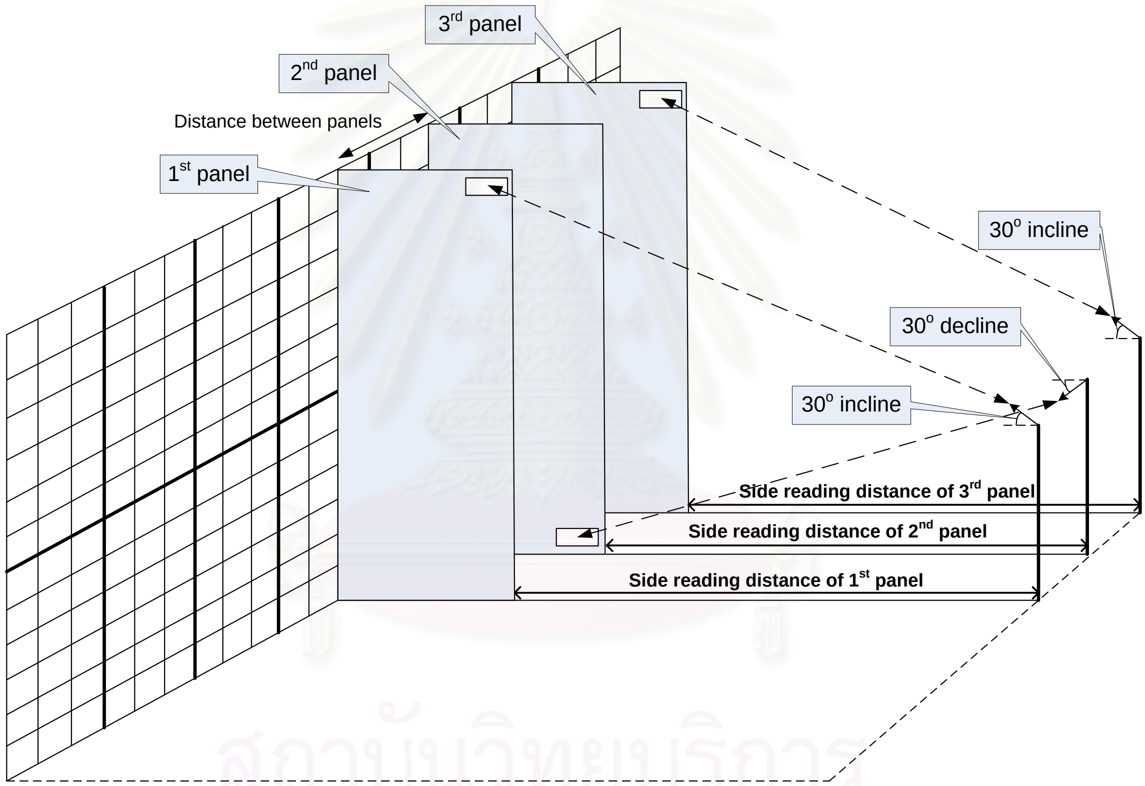


Figure 5.21 Simulation of placing three precast panels in A-frame

Regarding to the previous result of simulating the placement of 2 precast panels in A-frame, increasing the spacing between panels will not much help in reducing interference between tags which were mounted on adjacent panels. A solution was then proposed and the results were tested within this experiment. From the beginning series of simulations, the reader did not make any vertical angles, therefore the transmitted signal can reach those three positions (upper, middle, and lower) within reading distance. To prevent the reader read all those position within adjacent panels; in this last part of simulations, the reader was set up to make a 30^{o} angle both incline and decline (as described in **Figure 5.21**). It left one problem to be solved, the interference between tags which were placed with the same position on 1st and 2nd panels (as shown in **Figure 5.21**). Therefore this simulation was addressed to find best combination of placing two tags on odd or even-numbered panels. There were eight combinations that could possibly occur when placing all panels in A-Frame as shown in the **Figure 5.22**.

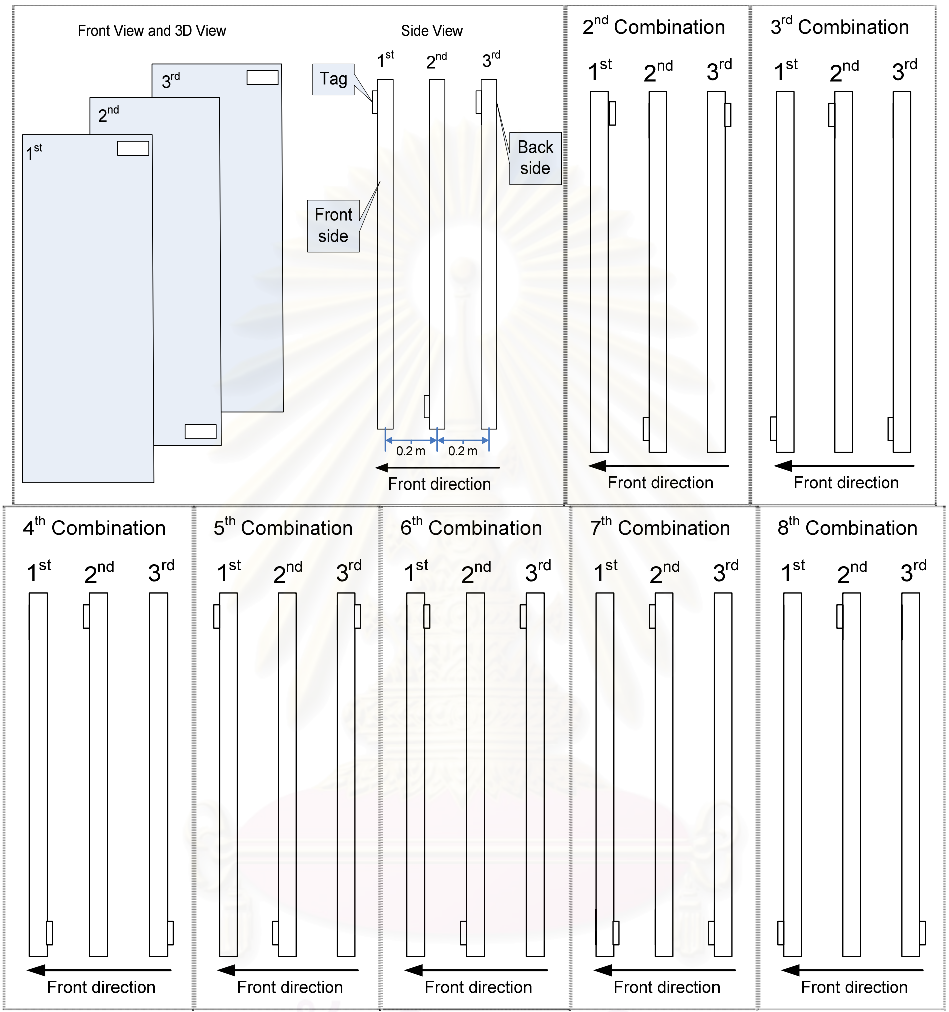
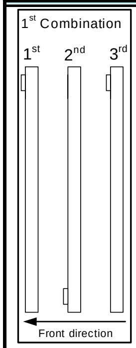
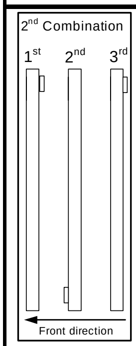
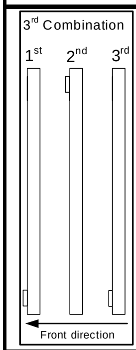
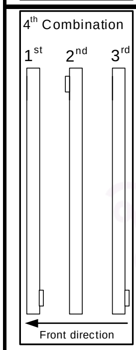
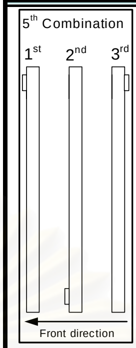
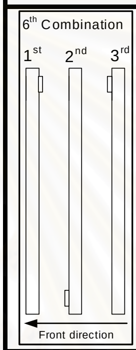
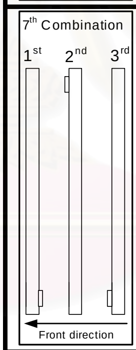
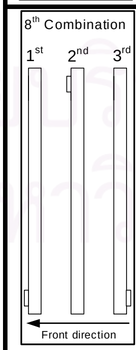


Figure 5.22 Combinations of tag position which attached on three adjacent precast panels

There are two results that were yielded from this simulation. Firstly, it yielded best combination of placing tags in three different panels whereas the second yielded best usage of portable reader in achieving the main purpose of these series of simulations which is interrogating panel one by one with out experiencing interference from other tags.

5.13.1 Data Collection on Simulation of Placing 3 Precast Panels on A-frame

Table 5.10 The collected data of the simulation of placing 3 precast panels on A-frame

Combination	Reading Direction	Reading Distance	Description
	1^{st} panel's side	1.91	read 1^{st} panel only, reading from 2^{nd} panel at distance 1.89 m yields 2^{nd} panel only
	3^{rd} panel's side	1.92	read 3^{rd} panel only
	1^{st} panel's side	1.94	read 1^{st} panel only
	3^{rd} panel's side	-	-
	1^{st} panel's side	1.80	read 1^{st} panel only
	3^{rd} panel's side	1.82	read 3^{rd} panel only
	1^{st} panel's side	-	-
	3^{rd} panel's side	-	-
	1^{st} panel's side	-	-
	3^{rd} panel's side	-	-
	1^{st} panel's side	2.02	read 1^{st} panel only
	3^{rd} panel's side	2.00	read 3^{rd} panel only
	1^{st} panel's side	1.97	read 1^{st} panel only
	3^{rd} panel's side	1.97	read both, reading from 2^{nd} panel at distance 1.82 m read both
	1^{st} panel's side	1.88	read 1^{st} panel only
	4^{th} panel's side	1.87	read 3^{rd} panel only

5.13.2 Analysis on Simulation of Placing 3 Precast Panels on A-frame

The 1^{st} combination

Three horizontally oriented tags were mounted on the 1^{st}, 2^{nd}, and 3^{rd} panel at the upper, lower and upper positions respectively. Side reading distance generated the detection of the 1^{st}, 2^{nd}, and 3^{rd} panels at 1.91 m, 1.89 m, and 1.92 m respectively. A relatively constant side reading distance from each interrogated panel allows the inspector to work in a narrower standing range. This combination satisfies the needs of the proposed RFID application within this research in which only the interrogated panel will give a response to the reader without experiencing interference from the other tags.

The 3^{rd} combination

This combination occurs when another two panels which were arranged in the form of the two last panels in 1^{st} combination were added behind the 3^{rd} panel of the 1^{st} group. The odd-numbered panels (1^{st} combination and another two panels were combined) have the tags mounted at the lower positions. The results have shown that the side reading distance is ranges from 1.80 m to 1.82 m. This reading range can be merged with the results of the reading range of the 1^{st} combination to form a wider-acceptable reading range (i.e., 0.1 m). The inspector will comfortably work at a range from 1.80 m to 1.92 m with a slight adjustment whenever interrogating a shorter reading distance panel.

The 6^{th} combination

This combination is yielded by moving the tag which mounted on the 1^{st} panel of the 1^{st} combination behind the current position. The side reading generated the detection at distance of 2.02 m and 2.00 m of the 1^{st} and 3^{rd} panel respectively from the associated panels. This combination can be repeated after a panel which is mounted with a tag at lower position is placed behind the 1st series of this combination. Therefore there will be two types of combination that are incorporated in the new combination which are 3^{rd} and 6^{th}. In this regard, the new combination has a certain level of complexity to be exercised (i.e., arranging the panels) instead of getting wider range of working range (i.e., 1.8 m to 2.02 m). The wider working range will drive the inspector to do adjustment whenever the inspector interrogates panel no. 4 and the multiplications of 4 (i.e., move to distance 1.80 m to 1.82 m) and back to distance of 2.02 m to 2.0 m for the rest of the panels.

The 7^{th} combination

The 7^{th} combination is formed whenever the mounted tag on the 1^{st} panel of the 3^{rd} combination is moved to the back side. The side reading was satisfying for the 1^{st} panel and resulted a 1.97 m of the reading distance. When the 2^{nd} and 3^{rd} panels were interrogated separately, the reader showed both (i.e., 2^{nd} and 3^{rd}) which is averse in the proposed RFID application. Apart from that, this combination will be repeated after a panel which is mounted with a tag at the upper position is placed behind the 1st series of this combination. Thus the 7th and 1st combinations are incorporated in the new combination. In this regard, the new combination has a certain level of complexity to be exercised. With regard to the aforementioned facts, the employment of this combination is not suggested.

The 8th combination

When the mounted tag on the 3rd panel of the3rd combination is placed behind the current position, the 8th combination is formed. The reading result which ranges from 1.87 m to 1.88 m conformed to the aim of interrogating the tag individually without experiencing interference from other tags though under certain condition. The panels can be interrogated from the associated sides except for the 3rd panel. The 3rd panel can be interrogated from the side of 4th panel rather than directly from its side. This combination will be repeated after a panel which is mounted with a tag at the upper position is placed behind the 1st series of this combination. Therefore the 8th and 7th combinations are incorporated in the new combination. Since the 3rd panel can be interrogated from the 4th panel side, this condition allows the inspector to interrogate two tags individually from the same position (i.e., the side of 4th panel). By rotating the reader vertically 30^o inclined downward and inclined upward, the reader will be able to interrogate 3rd and 4th panels respectively. With regard to the aforementioned facts, the employment of this combination is not completely suggested.

5.14 Resume of Test Results

The followings are the resume of the series of conducted test within this research. The resume comprises the findings (i.e., RFID general characteristics) from each test. The encompassed findings are expected to be utilized as guidance in applying RFID into construction industry.

Table 5.11 The resume of the findings

Test Title	Findings
1. Coverage Area	
1.1 Horizontally Rotated Reader	• The newly formed area tends to be smaller than previous area when the reader was horizontally rotated both in clockwise and counter-clockwise angles.
	• The boundaries (i.e., left and right most) move in line with the reader's horizontally rotating direction.
	• Whenever the left and right most boundaries of resulted area at one distance reached its actual limit, increasing the rotation angle will not make the boundaries of the newly formed area exceed those boundaries.

	• Lower boundaries are relatively stable whereas the upper boundaries are fluctuating.
	• The formed areas of vertically oriented tag are generally larger than horizontally oriented tags both in term of width and height.
1.2 Vertically Rotated Reader	• As the rotation angle incline upward, the newly formed area tends to be narrower than the previous area.
	• The upward rotation of the reader caused the upper and lower boundaries of newly formed area to move upward.
	• Generally, vertically oriented tag has larger area than horizontally oriented tags both in term of width and height.
1.3 Successful Reading Rate	• The successful reading rate tends to decrease as the distance increases.
	• Certain distances behave similarly in response to the transmitted radio wave.
	• The successful reading rates of vertically oriented tags are higher than horizontally oriented tags
1.4 Comparison of successful reading rate between maximum points and inner points	• Given at any conditions, the successful reading rate tends to decrease as the reading distance increases further.
	• The reading at inner points gives a higher successful reading rate than maximum points.
	• The successful reading rate of vertically oriented tag is higher than horizontally oriented tags.
2. Maximum amount of detected tags at once	• As the reading distance increases, the number of detected tags at once tends to decrease.
	• Center tag placement generates the maximum number of detected tags at once followed by lower and upper positions, consecutively.
	• Generally, vertically oriented tags yield a higher number of detected tags at once than horizontally oriented tags
3. Minimum spacing distance between tags to be read separately	• Center position tends to have a narrower spacing distance between tags as the reading distance increases.
	• Upper and lower positions generate the same graph pattern.
	• At the lower and upper positions of horizontally and vertically oriented tags, the curve tends to have wider spacing distance whenever it started with a narrower spacing distance.
	• Horizontally and vertically oriented tags generate graph that is in disagreement with one to another.
4. Simulation of placing 1 precast	• Both the front and 45^{o} angle reading directions have the same trend. The maximum reading distance increases and reaches

panel in A-Frame	the peak as the tag moved from upper to middle position and decrease thereafter. • Front reading distance generates a higher maximum reading distance than any other reading directions. • At upper position, all reading directions generate a relatively the same maximum reading distance associated to with its tag orientation. • Generally, vertically oriented tags yield further reading distance than horizontal ones.
5. Simulation of placing 2 precast panels 1 in A-Frame	
5.1 The measurements on 45^o reading direction and the projection line	• As the spacing distance between panels increases, both the reading distance on 45^o reading direction and the projection line increases. • Further distance within the reading range of the 1st panel limits the reading only to the 1st or without experiencing interference of 2nd panel.
5.2 Combinations of tag positions and tag orientations on panels	• The 6th combination of tag positions and orientations on the panels is considered as the best practice to meet the needs of proposed RFID application. Horizontally oriented tags are mounted on the 1st and 2nd at upper and lower positions respectively.
6. Simulation of placing 3 precast panels 1 in A-Frame	• The 1st combination is suggested as the best practice since it meets the needs of proposed RFID application. • The 1st combination leads to 3rd combination. • The working distance ranges from 1.80 m to 1.92 from the side of the associated panel.

The above listed findings are just a part of the RFID characteristics which were generated from this research. The aforementioned findings are perceived as general findings of RFID characteristics since most of the findings are unique therefore can not be generalized. From the general findings, can be concluded that there are several basic characteristics of RFID and are presented in the following section.

To encompass the aforementioned facts about RFID characteristics, the grand resume of RFID characteristics is presented as follows:

- As the distance increase, some of the RFID characteristics decrease their performances. These characteristics are comprised of the successful reading rate, the maximum amount of detected tags at once, and the minimum spacing distance between tags.

- For the overall characteristics, the vertically oriented tags have shown to have better performance than horizontally oriented ones. The coverage area, the successful reading rate, the maximum amount of detected tags at once, and the simulation of placing 1 precast panel in A-Frame are the incorporated characteristics to show the superiority of vertically oriented tags.
- Obviously, the center has the best performance than any other places in terms of consistency, reading distance, and the successfulness of reading rate. The closer the interrogated objects to the center of the transmitted signal, the better their performance. It is clearly shown from the results of successful reading rate, maximum detected tags at once, and simulation of placing 1 precast panel in A-Frame.
- For the coverage area, whenever the reader rotates either horizontally and vertically, the coverage are tends to be smaller compared with perpendicular orientation. The boundaries of the coverage area which are parallel to the rotation direction (i.e., left and right boundaries in the case of horizontal rotation and upper and lower boundaries for vertical rotation) tend to move in line with the rotation direction.

Some of the unique findings can be perceived as a corridor in applying RFID into the construction industry to get the best usage of RFID performance. These findings are presented in the form of recommendations in the next part of this chapter.

5.15 Discussions

The abovementioned RFID characteristics have a logical explanation why they occur, therefore some of them will be discussed briefly in the following parts.

a. The cause of decreasing performance as the interrogating distance increases

Some of the RFID characteristics tend to decrease their performance as the reading or interrogating distance increases. These characteristics are comprised of the successful reading rate, the maximum amount of detected tags at once, and the minimum spacing distance between tags. Path loss in transmitting radio wave signal either from the reader or feedback from the tags is the main reason why the performance decrease as the reading distance increases. The radio wave is transmitted through the medium (i.e., the air) and is attenuated. As the transmitting distance increases, the radio wave energy is getting weaker and fading away.

b. The cause of failing to read the tag

Since in RFID system, there are two phases in reading the tag. In the first phase, the signal (i.e., radio wave) is initialized by the reader and transmitted to the tag. Within the second phase, the received signal triggers the tag to send a feedback signal to the reader. Therefore the successful transmitted signal enables the reader to read the written codes from the tag. The failure in transmitting signal can occur in one of these two phases thus there will be two possibilities in case of reading failure. The first possibility is when the transmitted signal by the reader cannot reach the tag thus the tag will not give any feedback signal to the reader. Whereas for the second possibility, the signal successfully reached the tag but the transmitted feedback signal cannot reach the reader. Both possibilities yield failure in reading the tag.

c. The cause of the superiority performance of vertical oriented tag

Along the series of tests, vertically oriented tag has shown to have a superior performance compared to the horizontally oriented. This superiority is clearly noticed from the results of the coverage area, the successful reading rate, the maximum amount of detected tags at once, and the simulation of placing 1 precast panel in A-Frame.

The harmonization of polarization direction between transmitted signal from reader and feedback signal becomes the key of discussion in this issue. Radio wave, when it is transmitted, it consists of waves, namely: electric and magnetic waves. Both types of waves construct an electromagnetic wave and are placed perpendicularly one to another. The Intermec (i.e., tag's manufacturer) has noted that preferable tag orientation should be parallel with reader (i.e., antenna) polarization. In this case, both waves have its resultant at vertical direction (the major axis is placed at vertical direction). The vertical orientation has its polarization direction at vertical direction whereas horizontal at horizontal direction. The similarity in polarization direction makes the vertically oriented tags gives respond harmoniously (communicate easily) with the transmitted signal from the reader. This is the reason behind the superiority performance of vertical oriented tag above the horizontal ones.

d. The cause of the superiority performance at the center position

The tests have shown that the center position has a superior performance compared with the other positions (i.e. upper, lower, and other boundary points) in terms of consistency, reading distance, and the successfulness of reading rate. The superiority in performance have been shown from results of successful reading rate, maximum detected tags at once, and simulation of placing 1 precast panel in A-Frame.

Since the beam energy is focused at the center, the closer the interrogated objects (i.e., tag) are to the center of the transmitted signal, the better their performance. The results that have been generated from the center position are more consistent and reliable compared with others. The focused beam energy prevents the occurrence of errors (from any causes) to the tag reading.

e. The cause upon the issues on readable coverage area

The followings are the related issues to the coverage area. First issue that has been raised is the newly formed area tends to be smaller than previous area when the reader was horizontally rotated both in the clockwise and counter-clockwise angles. The area reduction occurs when entire boundaries tend to move in line with reader's rotating direction but some of the boundaries have reached their limits and cannot move further. Therefore the resulted coverage area tends to be smaller. The same reasoning can be applied for the case of vertically rotated reader.

The left and right boundaries (i.e., for horizontal rotation) and upper and lower boundaries (i.e., for vertical rotation) tend to move in line with reader's rotating direction. These boundaries are the representation of coverage area. The coverage area is defined as the area where if a tag is placed within the area, the tag will still be able to give respond to the reader. The beam direction will move as the reader is rotated either horizontally or vertically, therefore the response area also moves in line with the beam direction. The tag that is within the reader's sending range and still able to give feedback signal (i.e., response) to the reader will form the coverage area. This can also explain the case that whenever the left and right most boundaries of resulted area at one distance reached its actual limit, increasing the rotation angle will not make the boundaries of newly formed area exceed those boundaries. The tag at the outer boundaries might have received the transmitted signal and gave respond but the feedback signal cannot reach the reader for many reasons.

Compared with the lower boundary which is relatively stable, the upper boundary is fluctuated. The center of the reader is positioned at a height of 1.0 m above the ground. This center positioning might have caused the lower position might to not reach its actual limits whereas the upper position already reached its actual limits. Therefore the lower position is relatively stable.

f. The cause upon the issues on the series of simulations

The results of the simulation of placing 1 precast panel in the A-frame have shown that front reading direction has the furthest reading distance and then followed by 45^{o} and side reading directions. The response area takes place in explaining why the front reading yields the furthest reading distance than the others. The larger effective response area gives the stronger the feedback signal is produced. Thus the signal can be transmitted within further reading distances.

Some results have indicated that there are interferences between tags whenever they are mounted adjacent to each other on the panel/s. For example, within the series of tests of minimum spacing distance between tags, a further interrogating distance has caused narrower spacing distance between tags. The transmitted signal will be weaker as the interrogating distance increases thus the tag will receive less energy and also yield a feedback signal with a less energy. This less energy-feedback signal will cause a less interference with the other and focused to reach the reader.

Within the simulation of placing 2 precast panels in A-frame, tags that are mounted at the same position (i.e., upper position) on two adjacent panels interfere with each other. The reading distance has increased though the spacing distance between panels is increased. This kind of interference can be perceived as a constructive interference. It is predicted at certain distances beyond the investigated distances, the interference will fade away (i.e., reading distance will decrease) as the spacing distance become larger. Since the limitation of testing space, those distances cannot be investigated.

Another form of interference also occurred with the simulation of placing 2 precast panels in A-frame, where at certain combinations of tag placement, the resulting reading distances are further and shorter than when it is interrogated individually. Obviously, constructive and destructive interference have caused the further and shorter reading distance than individual ones respectively.

5.16 Affected factors to RFID performance

The aforementioned characteristics of the RFID are affected by many factors. As investigated from this research, the tag orientations, tag positions, distance, and interrogation angle, and the presence of other tags (interference) affects to the RFID performance.

The material where the tag is mounted on also has a big effect to the reading distance. Preliminary investigations were carried out in selecting the suitable materials as the media. Brick walls and metals do absorb the radio wave since both materials yield very short reading distances, ranging from 0.5 m to less than 1.6 m. The light weight wall made from gypsum material yields maximum reading distance up to 2.29 m. Styrofoam yields 2.4 m as the maximum reading distance, therefore it was selected as the test material. Note that the reading distance is measured based on horizontally oriented tags.

The environments also have a major impact to the RFID performance. RFID performance is affected by electrical noise and interference that may be present in the environment. In addition, it is essential to understand the fundamental properties of radio wave such as reflection, refraction, diffraction, and multipath. The multipath can cause high fields (extended further reading distance and coverage area) and low fields (null region).

In this regard, there are many things should be taken into account before going further into applying RFID for the construction industry.

5.17 Recommendations

To get the best usage of RFID, the unique findings are presented in the form of recommendation. The following recommendations are classified based on the types of RFID.

Maximum reading distance

The findings show that the maximum reading distance is up to 2.4 m. It is possible to do the reading further than 2.4 m but the occurrence of successful reading will be very low. The research divided the reading range in intervals of 0.5 m and resulted 5 points of observation. Each distance generated unique findings and can be useful if it meets the needs of the proposed application. It is recommended to understand the requirement of application before going further to set up the working distance.

Coverage Area

For horizontal rotation, the maximum of total coverage area of horizontally oriented tags was reached at the distance of 1.0 m then followed by 1.5 m, 2.4 m, 2.0m, and 0.5 m. Whereas for the vertically oriented tag, the total coverage area tends to be larger than the previous as the distance decreases from 2.4 m to 1.0 m and become smaller thereafter. For the vertical rotation, the trend follows the horizontal rotation. Since the coverage area tends to be smaller whenever the reader rotates either horizontally and vertically, it is suggested to avoid directional reading.

The successful reading rate tends to increase as the reading distance decreases. The selection of a working distance should be made based on the needs of the application. A level of accepted successful reading rate should be defined to get optimum performance (i.e., further reading distance with acceptable level of successful reading rate).

Maximum Amount of Detected Tags at Once

Horizontally oriented tags tends to have higher maximum amount of detected tags as the distance decreased but generates constant value at distances 1.5 m and 2 m. Whereas vertically oriented tag tends to rise in accordance with the distance and reach the maximum at distance 2 m and decrease thereafter. The suitable selection of tag orientation and working distance depends on the application’s needs.

Minimum Spacing Distance between Tags

Both horizontally and vertically oriented tags have the same trend of upper and lower position. But the trend is unique and can not be used as guidance. The center position has consistent trend which tends to have a narrower spacing distance as the distance increases.

Simulation of Placing 1 Precast Panel on A-frame

Vertically oriented tags tend to have a higher reading distance compared with horizontally oriented ones. For horizontally oriented tags, both front and 45^o reading reach the maximum reading distance at the middle position whereas side reading reach the minimum at the middle position. For vertical orientation, the front and 45^o reading have the same trend as the horizontal orientation whereas the side reading tends to decrease as the tag is moved to the lower position. Vertical orientation generates further reading distances than horizontal orientation. This can be an obstruction for those who want to interrogate the tag individually; therefore the selection should meet the needs of the application.

Simulation of Placing 2 Precast Panels on A-frame

The first part of the simulation results show that increasing the spacing distance between panels until certain distance will not reduce the interference from another tag which is mounted at the same position. The solution to this problem is to place the tags separately (i.e., upper and lower positions). Therefore in the second part, this solution is investigated through several possible combinations to get the best practice of placing tags on 2 adjacent panels. The 2^{nd} part generated the 6^{th} combination of placing tags that yields less interference between tags. By placing two horizontally oriented tags on the 1^{st} and 2^{nd} panel at the upper and lower positions respectively (i.e., the 6^{th} combination), each tag can be interrogated individually at a consistent distance.

Simulation of Placing 3 Precast Panels on A-frame

The simulation of placing 2 precast panels on the A-frame generated the 6^{th} combination as the best position of for detecting tags individually; therefore the tag placement is investigated through this simulation. Different from the previous simulation, in order to solve the interference problem, the reader is rotated 30 ^{o} inclined upwards and downwards which depends on the tag positions on the panel. The investigation shows that the 1^{st} combination is suggested to be implemented as best practice since it meets the needs of proposed RFID application. The 1^{st} combination leads to the 3^{rd} combination and both results in a working distance ranging from 1.80 m to 1.92 from the side of the associated panel.

5.18 Chapter Conclusions

This chapter presents the findings from an exploration of the RFID characteristics to provide a basic knowledge about RFID characteristics as guidance in implementing RFID for construction industry particularly in the precast installation process. The findings can be classified as general and unique RFID characteristics.

Some of the characteristics tend to decrease as the reading distance increase such as reading rate, the maximum amount of detected tags at once, and the minimum spacing distance between tags. The vertical tag orientation tends to perform better than the horizontal tag orientation. The center position has a better performance than any other positions. The coverage area tends to be smaller whenever the reader is rotated either horizontally or vertically.

The unique findings limit the usage of RFID since it behaves differently under various conditions. The unique findings create a corridor in implementing RFID. To find a proper use for the RFID, the working area should comply with the unique characteristics.

The RFID performance itself is also affected by many factors apart from its properties. Thus it is recommended for researchers to do further investigation on the working environment and interactions between RFID and the environment to meet the needs of the proposed RFID applications.

CHAPTER VI

THE DESIGN AND THE DEVELOPMENT OF RFID SYSTEM

This chapter aims to present the design and the development of RFID System to realize the conceptual model of RFID application in precast installation process. The RFID System attempts to show the importance of the two proposed types of information, namely related jobsite information and feedback information towards process improvement. Therefore, the involved parties along the precast installation process and their requirements upon information are identified prior to proposing the framework of RFID System. Three important events, namely the departure, the arrival, and the installation are found and utilized to collect their associated information. The framework of RFID System encompasses three modules, namely: pre-input, input, and output. The design and the development of RFID System correspond to the proposed framework and reflect the work sequence within precast installation process. The collected information is presented in the output module which incorporates Panel Information, Reports, and Analysis on Installation. The Panel Information displays detail information of precast panel whereas the Reports display the information that is associated to the three events separately. In addition, the Analysis on Installation utilized the associated information to installation event and presents the information into Table View and Graphical View. Both Table and Graphical Views present the recorded installation time based on panel type, house number, and completed house. Afterwards, the possible uses of the output and its benefits are presented consecutively.

6.1 Background

The Literature Review has revealed that information is essentially required for process improvement given the importance of two defined types of information which are related jobsite information along the process and feedback information in streamlining the process. How these types of information can streamline the process towards process improvement has been illustrated within the conceptual model of RFID application in prefabrication installation process. The conceptual model was made with assuming that both types of information are available and ready to be utilized.

In the current practices, although these two types of information are essential for process improvement, construction process has faced barriers in obtaining this information. The unavailability and difficulty to capture and store the information of the current practices have become the impeding factors in obtaining feedback information. Apart from that, the out of date, untimely, and inaccurate information have hindered the advantages of providing related jobsite information as if it is delivered appropriately along the process. Therefore, the presence of a system that can perform in such ways to overcome the associated barriers in obtaining these types of information is crucially required.

In this regard, a system namely RFID System is proposed to support prefabrication installation process by overcoming the barriers in obtaining those types of information. The RFID System consists of two major components, namely: RFID and the database. The RFID is utilized to perform data collection by identifying selected precast panel automatically whereas the database is used to store the collected data and hold the required information. In addition, the RFID System manages and presents the information in an informative approach.

Beyond the RFID System, queries may arise on how the RFID can support the precast installation process. The type of information that can support the precast installation process, the involved parties whose provide and require the information, the information availability, how to obtain the information, and how to access the information are being specifically queried. The types of required information have to be identified, the information availability has to be ensured, the method in obtaining and accessing the information have to be concerned. Therefore, those queries are incorporated within the designing of RFID System to fully accomplish the objectives of RFID application in precast installation process. The RFID System is expected to generate these two types of information to streamline the precast installation process towards process improvement.

6.2 The Objective

The design and the development of RFID System towards the realization of conceptual model of RFID application in precast installation process have the following objectives:

- Identify the involved parties and their required information along the precast installation process.
- Enable the involved parties in collecting the data and accessing related information to support precast installation process.

The two outcomes, namely: the user interface of RFID System and the generated information are expected to be helpful in streamlining the decision making process and construction process. The RFID System allows users in collecting, stored, and accessing the required information. The stored information is presented in an informative approach to help users to have a better understanding about precast installation process, a prompt decision making process, and as feedback information for further analysis towards process improvement.

6.3 Scope of the Work

As previously mentioned in the conceptual model of RFID application in precast installation process, several processes have been defined and incorporated within this conceptual model. The series of process are commenced from the departure of precast panels from the manufacturer, the arrival of the precast panels at the construction site, the storage of the precast panels, and the installation of the precast panels. The defined series of process became the scope in conducting the stages in designing and developing the RFID System.

Therefore, the identification of involved parties and their requirements upon information, the design and the development of RFID System, and the possible usage of the generated information are limited to those defined series of process. The involved parties along the defined series of process and their needs upon information are identified prior to the design and the development of RFID System. The design of RFID System was made to reflect the defined series of process by concerning about at least three events which have been identified, namely: Departure, Arrival, and Installation. The possible usage of the generated information which can be perceived as an output is identified afterwards based on the involved users along the defined series of process.

6.4 Methodology

Three stages are involved in the design and development of RFID System, namely: identification of the involved information that associated to the involved parties along the defined series of process, the design and the development of RFID System, and the possible usage of the generated information to the involved parties. The outline of how the design and the development of RFID System were conducted is shown in the **Figure 6.1** below and its details are described in the following section.

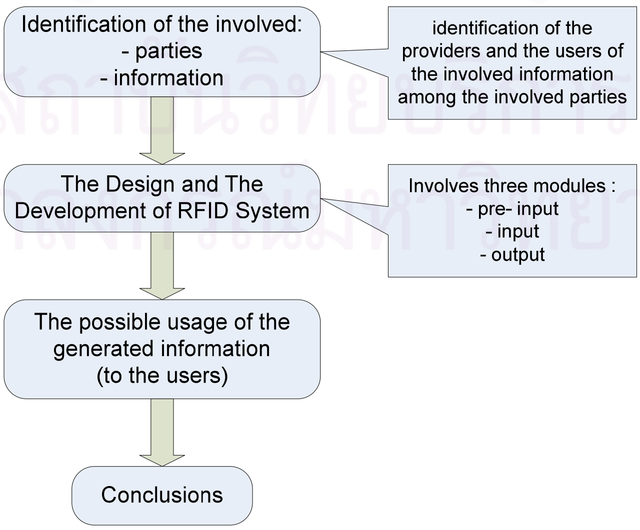


Figure 6.1 Methodology of The Design and The Development of RFID System

The given series of process can be translated into three main events, namely: the departure, the arrival, and the installation. On these three events, the involved parties have to be identified prior to the identification of the required information. Depart from the identification of involved parties; the identification of their requirements upon information and both of the providers and the users of the required information have to be made. The results are the basis in determining the framework of RFID System which is composed of three main modules, namely pre-input, input, and output. The modules reflect the sequence of the series of process. Information that relates to the properties of precast panel which can be defined prior to the departure event and either by the manufacturer and the management is perceived as a pre-input. The input itself is defined as the information that is collected along the three defined events. The collected data is then stored at the database and when the involved parties are in the needs of accessing the information, it will be presented informatively in form of reports and basic analysis to support the precast installation process. The possible usage of generated information to the identified users is identified and presented afterwards.

6.5 Identification of Involved Information

Before going further with the design and the development of RFID System, the involved information and associated parties have to be clearly recognized. In advance, the objects of observation are limited to the given scope, i.e., the defined series of process. The defined series of process can be translated into three main events, namely: the departure, the arrival, and the installation. At each of these events, the involved parties and their requirements upon information are identified (as shown in the **Figure 6.2** below). In addition, the providers and the users of associated information are identified to determine the information flow.

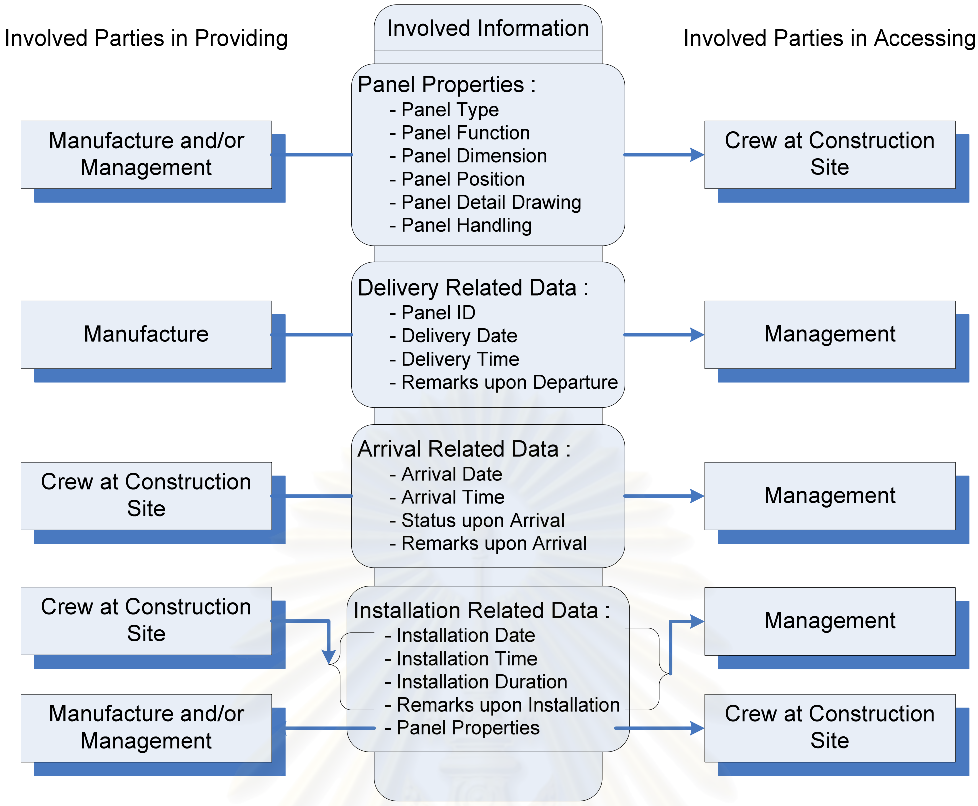


Figure 6.2 The identification of related information, providers, and the users

As described within the **Figure 6.2** above, there are three groups of the identification results, namely: the involved information at each event, the providing and the accessing parties of associated information. Both providers and users are composed of at least three parties, i.e., manufacturer, management, and crews at construction site. Each of them provide and require certain information at particular time. These results are utilized as a basis in designing RFID System.

The results determined how RFID System will perform in facilitating the needs of information. RFID System adjusted itself with the current work sequences in determining its components and learning the information flows among the involved parties. Thus, RFID System will be able to determine when to collect the information, to which party the data collection is addressed, and what information that has to be collected. Afterwards RFID System will determine when, to whom, and which information that have to be presented in supporting the precast installation process. The details of the design and the development of RFID System are presented in the following parts.

6.6 The Design and the Development of RFID System

The design and development of RFID System aims to translate the conceptual model of RFID application into practical form. Therefore, the components of the conceptual model have to be identified prior to the design. At least there are three components are incorporated within the RFID application, namely: the involved information, the providers and the users of the information, and the system that can bridge the two aforementioned components. The identification of the involved parties and associated information are previously discussed within the previous section. Depart from the identification stage; the RFID System is designed to facilitate the involved parties in collecting and accessing their required information to support their activities within precast installation process.

The RFID System consists of two components, namely: the RFID and the database. The RFID is utilized as an automatic identification tool to collect the field data whereas the database is used to store the collected data. The data in database can be retrieved to provide information for making decisions. Together, they form a system that can collect the required information, hold the information, and present the information in an informative approach to support the precast installation process towards process improvement. The framework of RFID System is presented in the following section.

In regard with the defined series of process and the involved parties and associated information, the framework of RFID System has defined three modules to distinguish on when the information is collected and presented. These three modules also imply the work sequence within precast installation process. As illustrated in **Figure 6.3**, the three modules are the definition of panel type properties as pre-input, the input, and the output. Though the pre-input and input modules are basically have the same aim which is to collect the required information, the pre-input implies that associated information can be entered in advance of three defined events and does not affected with the activities upon the precast panel. The three defined events, namely: the departure, the arrival, and the installation represent the defined series of process. The input module collects the required information at and associated to each of these events. The collected information reflects the occurrence of each time a precast panel reaches those events.

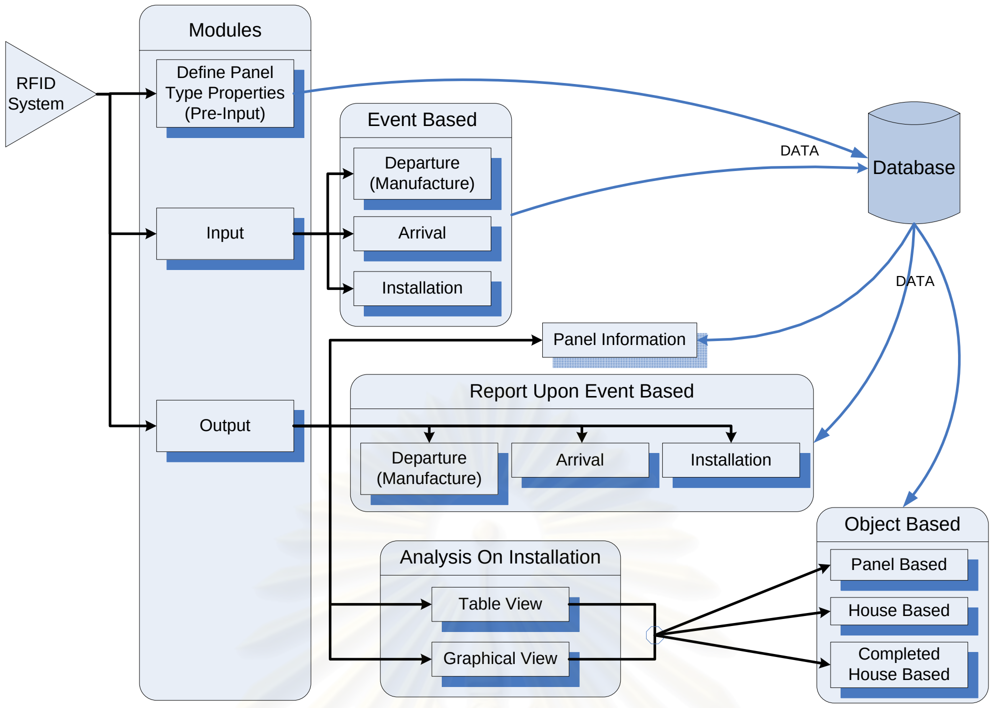


Figure 6.3 The framework of RFID System

Lastly, the output is presented within three forms, namely panel information, the report upon event based, and analysis on installation (as seen in **Figure 6.3**). The panel information presents the information about the panel itself which is not depend on the activities upon the panel. The presented information included the panel type, the function, the dimension, the position on the layout drawing, the detail drawing, and the handling. The reports are generated based on the three defined events and aim to give details about the occurrence of each event that has been experienced by precast panel.

Since the RFID System also intends to emphasize more on the recorded installation time, the analysis on installation is presented in two approaches, namely: table view and graphical view. The table view presents the information that corresponds to selected categories in table manner and is equipped with a set of descriptive statistic values such as the maximum, the minimum, the sum (total), and the average. The graphical view as implied from the name presents the information that corresponds to selected categories graphically. The graphical view allows user to have a profound analysis upon the presented information. Both table and graphical views present the information based on three categories which are panel based, house based, and completed house based. Panel based intends to compare the installation time of a particular panel type at different houses. The house based aims to compare the installation time of panel types at a certain house and the total duration to install panels in forming one complete house. The completed house based aims to compare the total duration of installation of completed house.

The RFID System also incorporates a database to hold the collected data which can be retrieved anytime when it is required. As previously mentioned, there are two modules of input are incorporated within RFID System which are pre-input and input. The pre-input, i.e., the definition of precast panel type properties can be defined in advance of the three defined event since it does not response to the occurrence of those three events or in other words relatively static when is compared with the input that associated to the events. In addition this set of information can be used as a reference when the users interrogate the panel properties. Therefore the set of information that are incorporated to pre-input are stored in a separate table with the input. The table that contains the pre-input information is labeled as "Panel Type" and holds the information as shown in **Figure 6.4**.

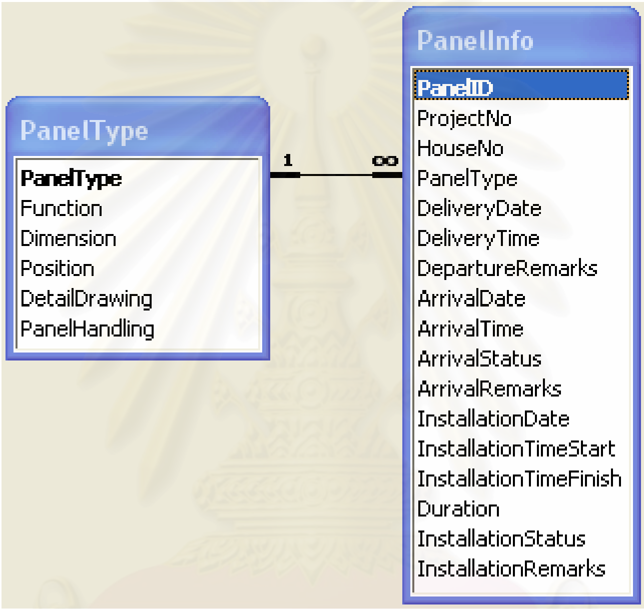


Figure 6.4 Components of "Panel Type" and "Panel Info" tables and their relationship (the schema for RFID System database)

The input holds the data that associated to the three events which are the departure, the arrival, and the installation (as seen in **Figure 6.4**). Each panel can be identified by its unique identification number, i.e., "Panel ID". Within this research, the Panel ID is assumed to hold 9 digits of characters. These 9 digits of characters incorporate Project No.(i.e., the first three digits), House No.(i.e., the second three digits), and Panel Type (i.e., the last three digits). Each panel will have three set of data that associated to the three events. A table that is labeled as "Panel Info" holds these three set of data.

The output components mostly retrieve their data from "Panel Info" table particularly the reports upon event based and analysis on installation. Unlike the other types of output, the Panel Information retrieves data from two tables, i.e., "Panel Type" and "Panel Info", at the same time. The relationship between tables allows the user to refer some data that is stored in another table. The relationship between these two tables is defined as "one to many" relationship as described in **Figure 6.4**.

6.6.1 The Main Menu

The Main Menu will be the first menu that users can interact with. The Main Menu is designed in accordance with the framework of RFID System. Users are allowed to explore the contained features of RFID System by interrogating each of the available menus. The available menus which are directly seen in the toolbar can be perceived as 1st level menus. The 1st level menus represent the group of features which are started from the pre-input, input, and the output. In addition, the 1st level menus' arrangement implies the sequence of the work which will guide the users to fully utilize the offered features of RFID System.

As described in **Figure 6.5** below, there are seven of 1st level menus, namely: Define Panel Type, Quantity & Quality Checking, Panel Installation, Panel Information, Reports, Analysis on Installation, and Exit menus. As previously argued that the Define Panel Type, i.e., pre-input contains data which can be collected prior to the three events and the information will be accessed sometime after the departure event. Therefore, the Define Panel Type is placed on the left most hand part of the toolbar to imply the very first set of data that have to be collected.

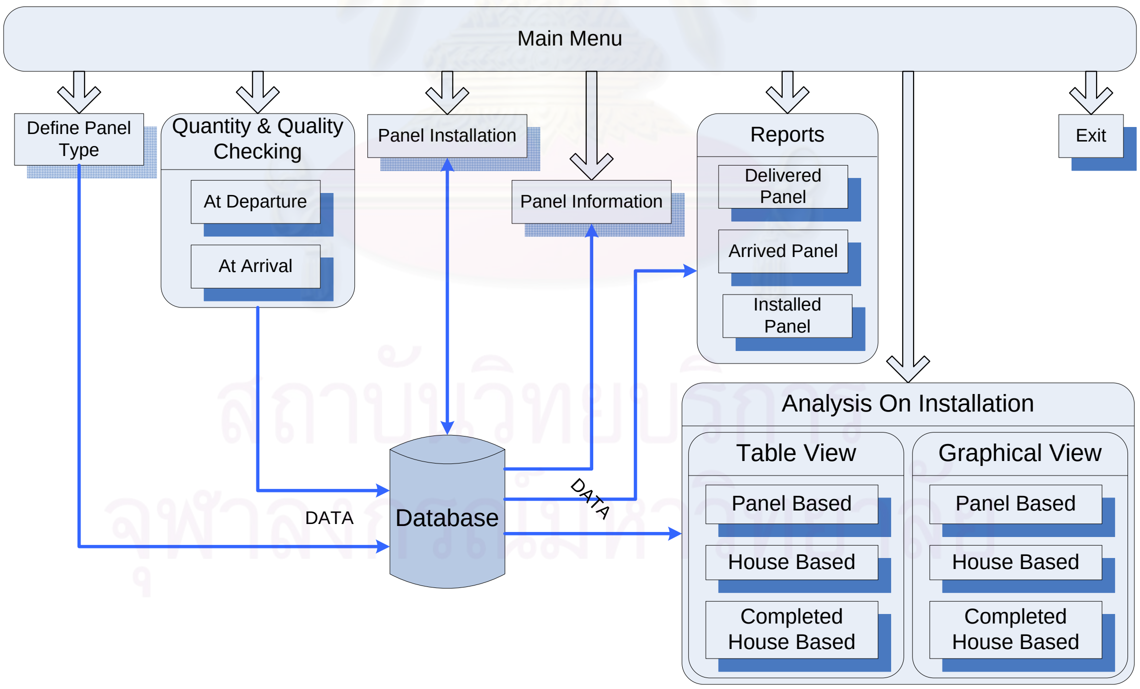


Figure 6.5 The hierarchy of available features on RFID System

The input menus are separated into two of 1st level menus, namely: Quantity & Quality Checking and Panel Installation (as shown in **Figure 6.5** above). This separation is made based on the objectives of each of the events. The departure and the arrival events aim to identify the delivered and arrived panel respectively in terms of quantity and quality whereas the installation aims to identify the next panel to be installed based on the panel installation sequence and the current available and installed panels.

As illustrated in **Figure 6.5** above, the output menus are classified into three of 1st level menus, namely: Panel Information, Reports, and Analysis on Installation. The difference in the types of information and presenting approach has made this separation. The Panel Information presents details about technical properties of Panel Type. The general information that has been collected during the three events is presented separately within the Reports based on the associated events. A further analysis on recorded time of installation is presented both in a table and graphical views under the Analysis on Installation as the 1st level of menu. Lastly, 1st level menus are ended with the Exit menu to terminate the RFID System. The details of each menus and submenus are presented in the following sections.

6.6.2 Define Panel Type form

As previously discussed, the Panel Type and associated information have to be defined sometime prior to the departure even either by the manufacturer or management. Therefore within the main menu, the Define Panel Type is the first form to be filled. The collected information is ready to be accessed sometime after the departure event. The collected information is translated as the detail properties of the panel.

As illustrated in **Figure 6.6**, the detail properties encompass the panel type, the function, the dimension, the layout position (in form of figure), the detail drawing, and the panel handling (in form of video). The panel type consists of two elements, namely: the type of house, and the panel number. A project may have several types of houses therefore the panel designs are distinguish one to another. The panel number indicates the installation sequence in forming a complete house. The panel function can be either slab or wall. The layout position informs the position of associated panel at particular storey that is presented in form of a figure. The detail drawing presents the components of a particular panel such as windows frame if any, door frame if any, utilities ducting, and joints. The panel handling presents the method of lifting and placing the associated panel in form of video.

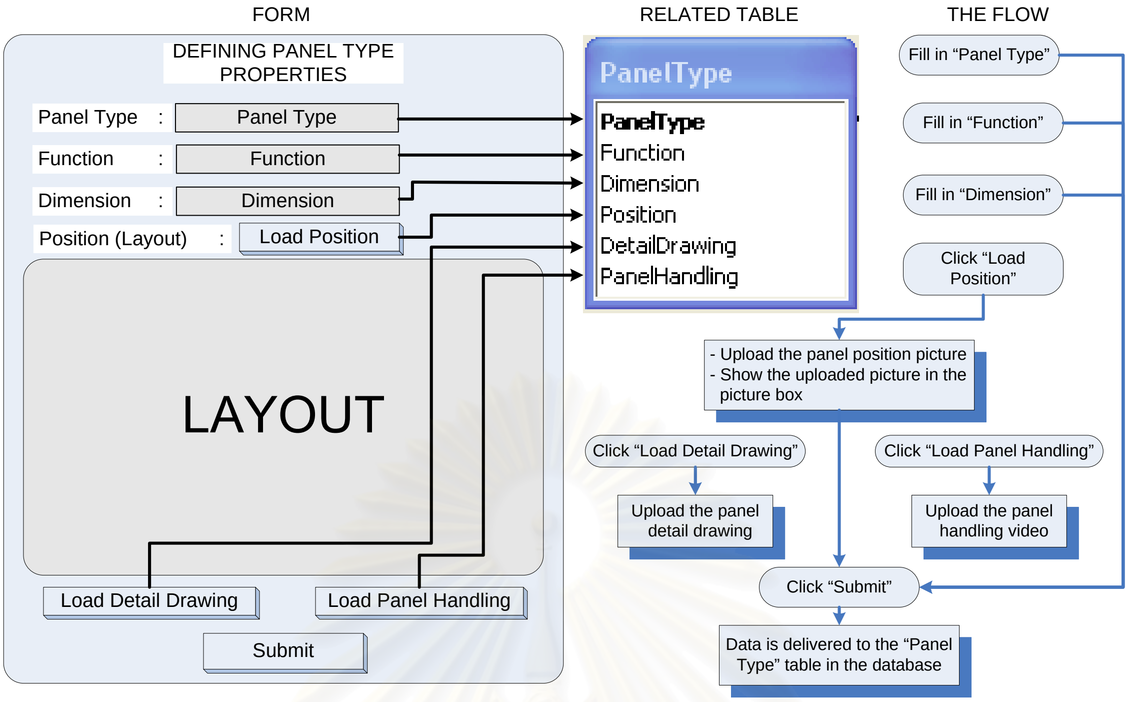


Figure 6.6 The Define Panel Type form

The stages in completing the form are presented in **Figure 6.6** above. The collected information is then stored at the database particularly "Panel Type" table. This set of information can be accessed afterwards whenever the users interrogate the panel by using the "Panel Information" form.

6.6.3 At Departure form

After completing the pre-input, now the users are ready to collect data that associated to the three events, namely the departure, the arrival, and the installation. Each panel has to go through these three events. Therefore each panel will have three set of information that are captured from the occurrence of those three events. The first event is the departure which is defined as the event when the precast panel leaves the manufacture to be transported to construction site. Therefore the departure form will be the first input among the three events.

The Departure form aims to capture information that associated to the departure event. As described in **Figure 6.7**, the associated information incorporates the departure date, departure time, and remarks upon the departure of the panel that is being interrogated. Once a particular panel is being interrogated whenever it departs the manufacture, the RFID System will automatically confirm the information about the Panel ID of the interrogated panel and capture the date and the time of the departure event. The confirmed Panel ID will be automatically decoded into Project No., House No., and Panel Type. Remarks upon the departure can be typed in the allocated textbox.

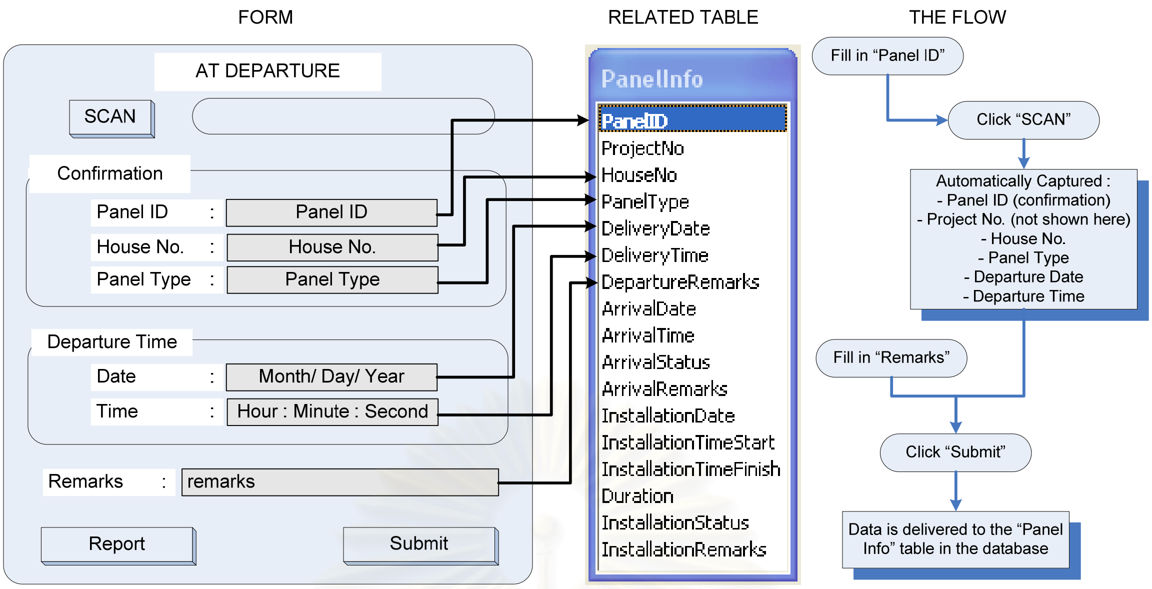


Figure 6.7 The Departure form

The steps in completing the form are presented in **Figure 6.7** above. The collected information is then delivered to the database particularly "Panel Info" table to be stored whenever the "Submit" button is pressed. This set of information can be accessed afterwards whenever the users require checking the report of the delivered panels by clicking the "Report" button.

6.6.4 At Arrival Form

The arrival event is marked whenever the delivered panel reached the construction site. Crews at construction site are required to collect information that associated to the occurrence of arrival event by using the arrival form. The arrival form will be the second input among the three events.

The associated information upon the arrival event incorporates the arrival date, arrival time, status on arrival, and remarks upon the arrival of the panel that is being interrogated (as shown in **Figure 6.8**). Similar to the departure form, RFID System will automatically confirm the information about the Panel ID of the interrogated panel and capture the date and the time of the arrival event once a particular panel is being interrogated whenever it arrives at construction site. The confirmed Panel ID will be automatically decoded into Project No., House No., and Panel Type. Status on arrival can be selected either accepted or repaired even rejected based on the evaluation upon the panel quality. Remarks upon the arrival can be typed in the allocated textbox.

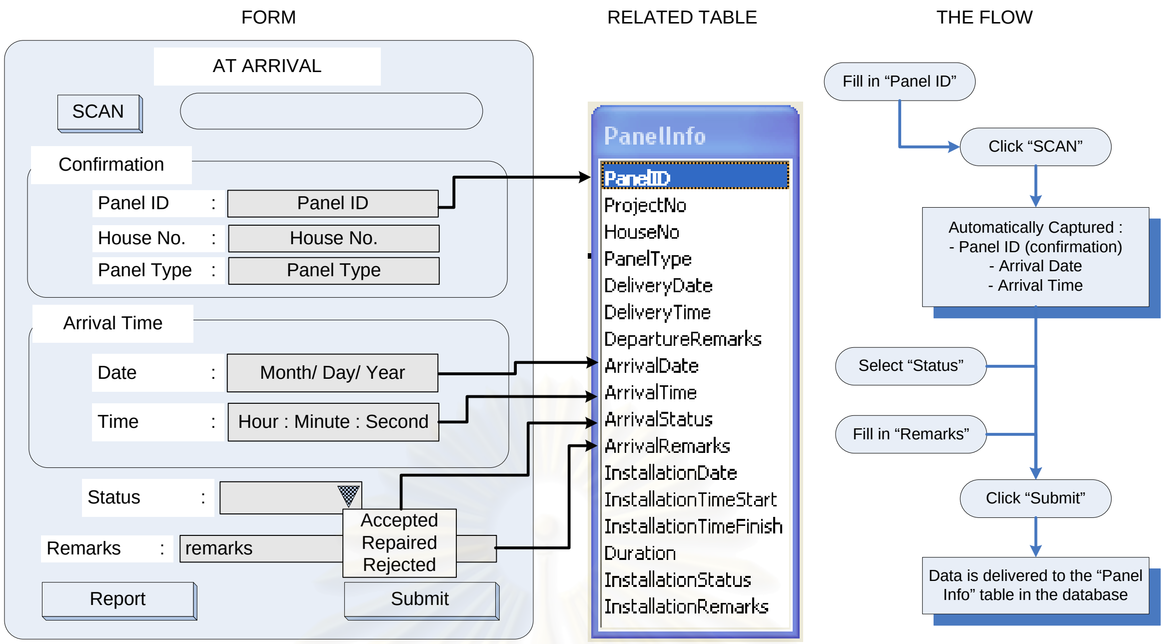


Figure 6.8 The Arrival form

Figure 6.8 above presents the required steps in completing the Arrival form. The collected information is then delivered to the database particularly “Panel Info” table to be stored whenever the “Submit” button is pressed. The users can access the information about the arrived panels and its associated information which is presented within the arrival report by pressing the “Report” button.

6.6.5 Panel Installation Form

The last event among the three events is the installation stage. There are two phases that are encompassed within the Panel Installation form. The first phase aims to find the next panel to be installed whereas the second phase aims to capture the installation date and the lifting duration.

In advance, the users have to select the house that is being worked on. Then the first phase is started by querying the available panels and installed panels of selected house. As shown in **Figure 6.9** below, the query displays the list of available panels which have either accepted or repaired as their status on arrival and also the have been installed. In addition, the query determines which available panel will be installed next based on the installation sequence. The detail information of the next panel to be installed can be accessed by pressing “Info” button. The “Panel Information” will be displayed in accordance to the selected panel.

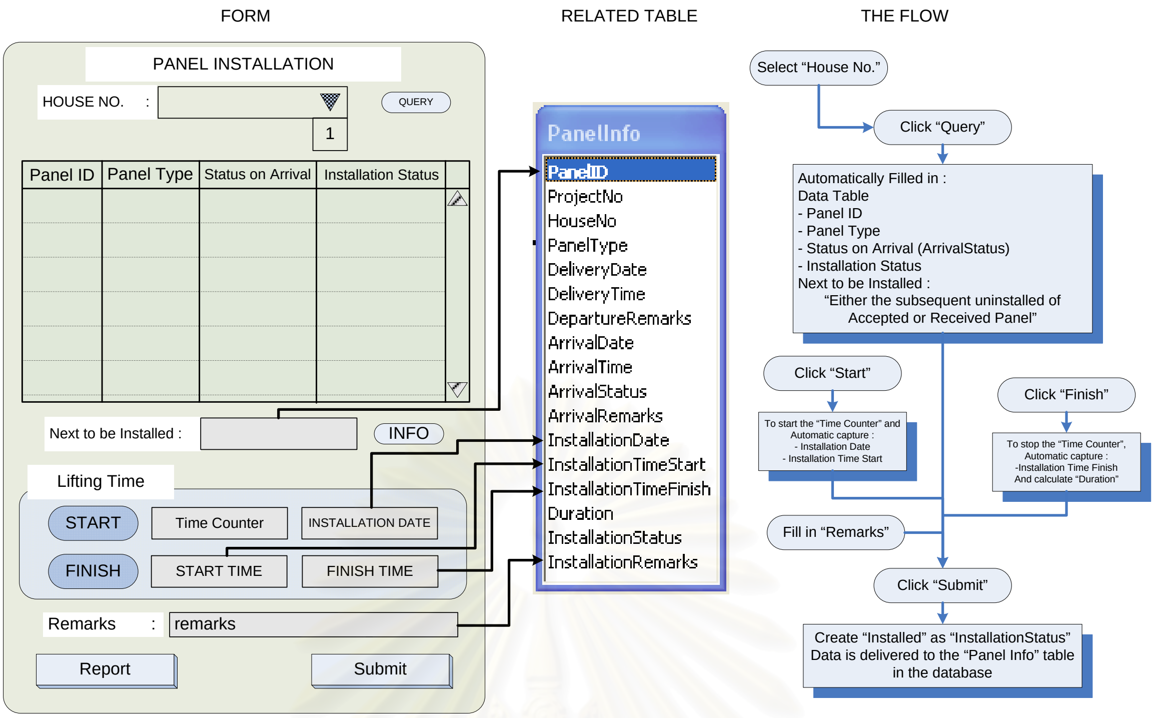


Figure 6.9 The Installation form

After finding the next panel to be installed and completing the preparation work that have to be done prior to the lifting phase, the RFID System is ready to collect data that associated to the installation event. The associated data incorporates the Panel ID, installation date, the starting time of installation, the finishing time of installation, the installation duration, and remarks upon the installation. By clicking the "Start" button, the RFID System will automatically capture the current date and starting time and start the time counter. As the lifting phase finished, clicking the "Finish" button will capture the finishing time, stop the time counter, calculate the installation duration, and generate "installed" as installation status. Afterwards, the remarks upon the installation can be typed in the allocated textbox.

As shown in **Figure 6.9** above, the collected information is then delivered to the database particularly "Panel Info" table to be stored whenever the "Submit" button is pressed. The users can access the information about the installed panels and its associated information which is presented within the arrival report by pressing the "Report" button.

6.6.6 Panel Information Form

The Panel Information is one of several outputs that are provided within RFID System. The components of Panel Information are mostly accessed from the pre-input whereas the other output such as reports and analysis on installation are fully rely on the information that is generated from the input. The details of Panel Information are presented in the following sections.

Sometime the users need to interrogate a particular panel to identify the detail information of the associated panel prior to the installation which helps them to perform their tasks. Therefore, the presence of "Panel Information" is important to equip the crews with sufficient information about associated panel. The provided information is directed to support the crews in performing their tasks.

As seen in **Figure 6.10**, the Panel Information involves two tables, namely "Panel Info" and "Panel Type" in providing the detail information of an associated panel. The detail information incorporates Panel ID, Project No., House No., Panel Type, Function, Dimension, Position, Detail Drawing, and Panel Handling. The first four mentioned components are retrieved from "Panel Info" table while the rest of the components are accessed from "Panel Type" table. The Panel Type links these two tables which enables the "Panel Info" table in referring the detail information about panel type to "Panel Type" table.

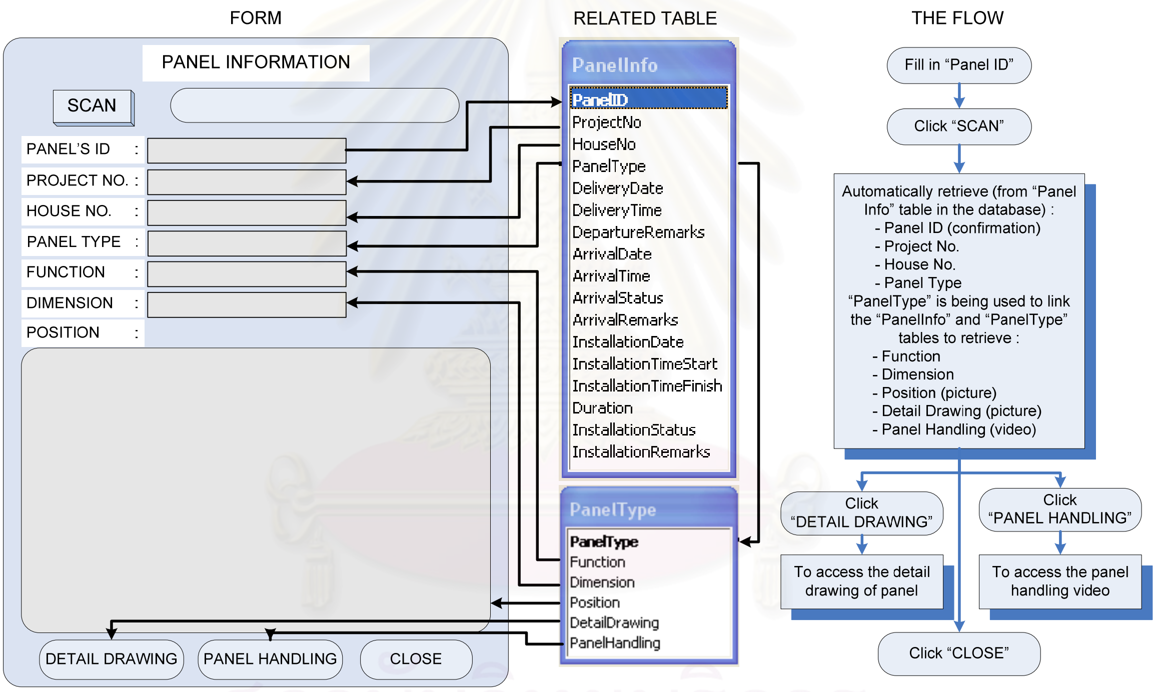


Figure 6.10 The Panel Information

There are two phases in presenting the Panel Information. The first phase is the main window of Panel Information which displays most of the detail information. The second phase is the two sub windows which appear only when they are required. The "Detail Drawing" and "Panel Handling" buttons display the respective information about detail drawing and panel handling. At each window, the users are allows to interrogate further more by using the provided buttons (as shown in **Figure 6.11** below).

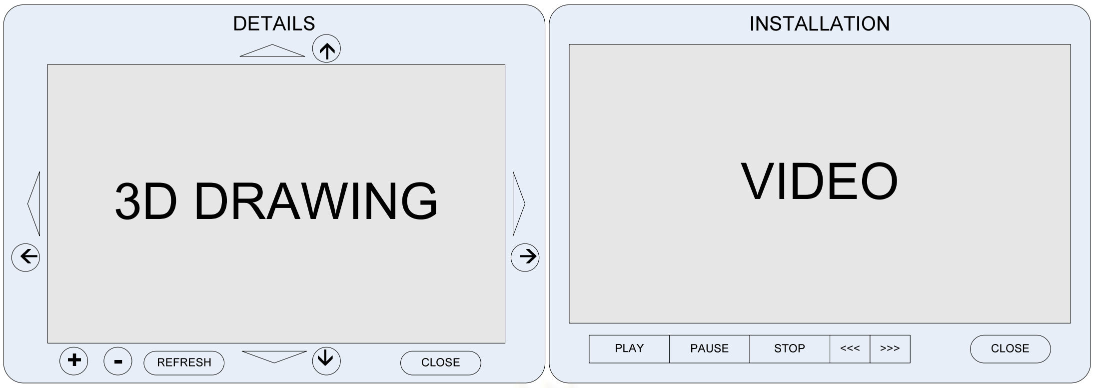


Figure 6.11 Two respective sub windows of Detail Drawing and Panel Handling

6.6.7 Report Forms

Reports are another form of the output which is incorporated within RFID System. The report is generated to present information about the panel and associated information based on three consecutive events. Therefore, there are three types of reports, namely: report of delivered panels, report of arrived panels, and lastly, report of installed panels. The information is presented in a table form. Most of the displayed information is retrieve from “Panel Info” table within the database.

The displayed information is generated by filtering the information based on the selected criteria. All the reports utilize the range of event’s timing as their basic criteria. Afterwards, specific information that complied with the given range of time is finally filtered by using either a particular or all houses to be finally listed on the table. A simple summary is presented in terms of the quantity of listed items. **Figure 6.12** describes the appearance of the report by using the report of delivered panels as an example.

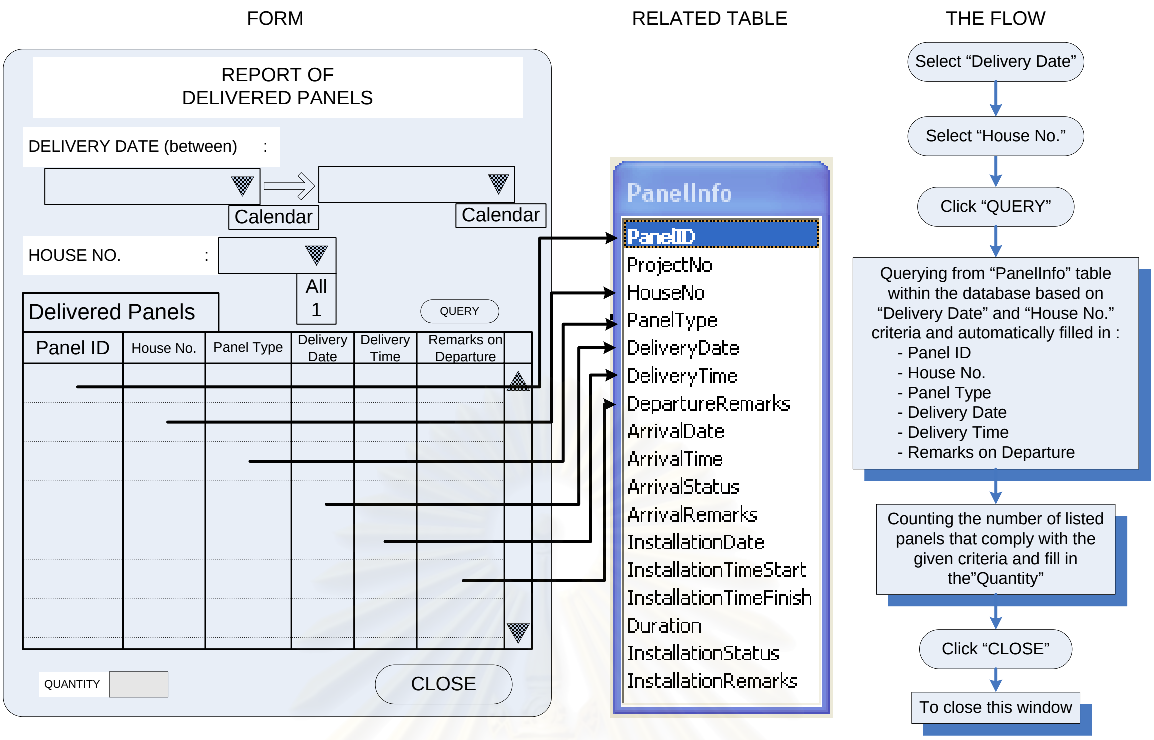


Figure 6.12 The appearance of the Reports of Delivered Panels

The structure of the other reports is basically the same. Their appearances are presented in detail in the **Appendix B7** and **B8**. The things that made them distinguish are the associated information of the listed panels and the items of quantity. On the reports of delivered panels, the displayed information consists of Panel ID, House No., Panel Type, Delivery Date, Delivery Time, and remarks upon the departure event. In addition, a summary is presented as the quantity of the listed panels. For the report of arrived panels, the displayed information is the same for the first three items of information. The rest of the displayed information is Arrival Date, Arrival Time, Status upon Arrival, and lastly, remarks upon the arrival event. As a summary, the quantities are presented based on the Status upon Arrival of the listed panel. Therefore, there are four quantities are displayed within this report, namely: quantity of accepted panels, repaired panels, rejected panels, and the quantities of the entire listed panel. For the report of installed panel, the distinguish items on the displayed information encompass the Installed Date, Installation Duration, and remarks upon the installation. To sum up, a quantity of the listed panels is displayed on the bottom part of the report. The installation duration time is being highlighted within RFID System since it enables the further study of precast installation process. Therefore, a simple analysis upon the installation duration time is presented in the next section.

6.6.8 Analysis on Installation

The installation is being an interesting part of RFID System. The recorded installation time can be perceived as feedback information about the current practice of precast installation process. As previously mentioned, the feedback information enables the management in evaluating the current performance. Problems origins can be traced and corrective actions can be performed. Though a profound study upon the recorded time will not be carried out within this research, RFID System will provide simple analysis to offer some idea on how the recorded installation time will be process to be useful in performing process improvement particularly on precast installation process. Analysis on Installation is presented in two approaches, namely: Table View and Graphical View. Each of these approaches has its own objective in presenting the recorded installation time. These two approaches complement one to another and will help the users to understand the displayed information. The details are discussed within Table and Graphical Views consecutively in the following sections.

6.6.8.1 Table View

The recorded installation time is presented in a table view. According to Zhang Li and Xiao-lan (2004), the following aspects can be perceived as the advantages of presenting data in a table view, namely: ease of taking statistics, full of data, accuracy of presentation, ease of calculation, greater adaptability for more data, details of presentation, systematization, ease of being made, baldness, difficulty of interpretation, and abstractness. As listed as the advantage of presenting information in a table view, users are enabled to perform descriptive statistic analysis. Descriptive statistic analysis facilitates users to understand the data through summary values. The summary values incorporate the sum (total), the average, the maximum, and the minimum. The table view also enables the data to be organized into groups.

The Analysis on Installation that is presented in table view which consists of three tables that based on the objects point of view, namely: panel based, house based, and completed house based. As implied from the name, the panel based table view allows users to observe the installation time of a particular panel that is installed in any houses. Whereas the house based provides users with the installation time of many panels that are incorporates in a particular house. In addition, the completed house based facilitates users to observe the total installation time of any completed houses. The displayed information is also furnished with either of the summary values, i.e., the sum (total), the average, the maximum, and the minimum.

As described in **Figure 6.13**, an analysis is made on panel based. The objects point of view become the criteria in filtering the associated information to the installation event. For instance, the panel based uses the panel type as the criteria whereas the house based utilizes the housed number as the criteria. The displayed information consists of the panel type and duration of installation. In addition when the panel type is being the criteria then the house number will be incorporated to the displayed information and vice versa.

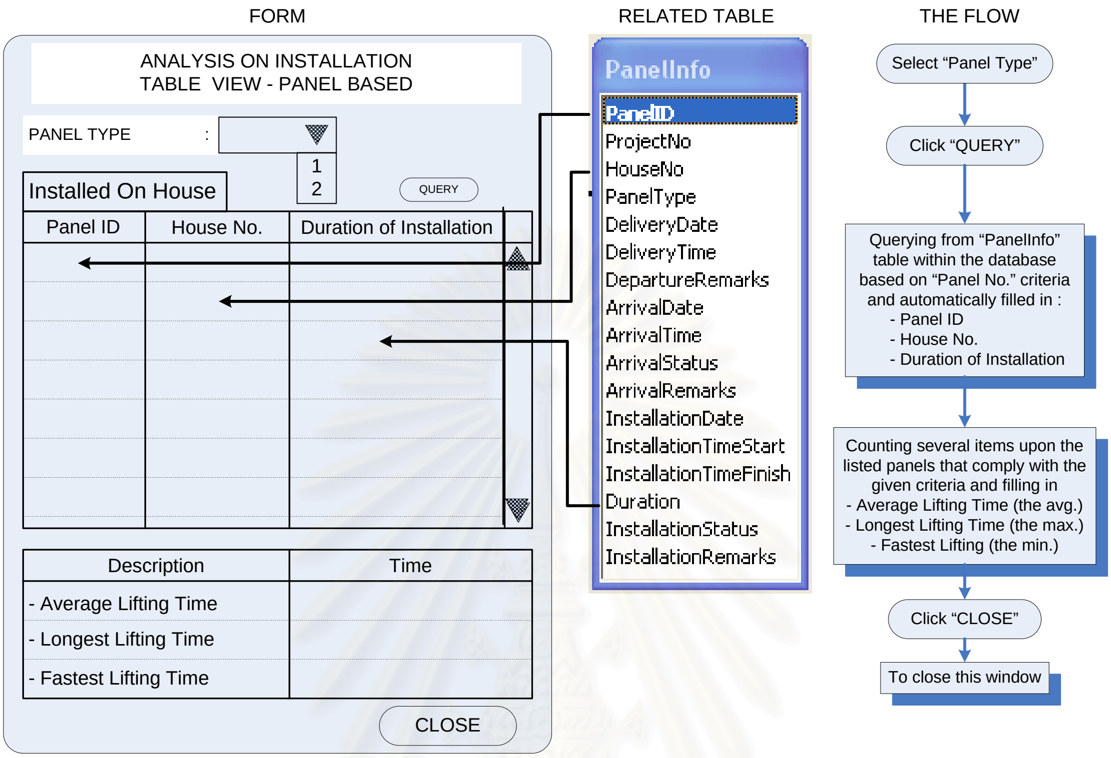


Figure 6.13 The appearance of the analysis on installation by using table view based on panel type criteria

As shown in **Figure 6.13**, the panel based analysis aims to compare the recorded installation time of a particular panel type which is installed in any houses. To understand the displayed information, summary values that are incorporated within this table view consist of average lifting time, the longest lifting time (i.e., the maximum), and the fastest lifting time (i.e., the minimum). For the house based analysis, since it aims to obtain the total installation that required in completing a particular house, the listed panels are the components of a particular house. To fulfill the objective of the house based analysis, the summary values incorporate the sum of lifting time (total), the longest lifting time, and the fastest lifting time. The detail appearance of the house based analysis is presented within the **Appendix B10.**

For the completed house based analysis, the objective of this analysis is basically in line with panel based analysis but at this stage the object of comparison is completed houses. The query will retrieve the information of total installation (lifting) time of completed houses and displays the results. The displayed results encompass the house number and the total lifting time. To achieve the objective of completed house based analysis, the summary values are presented and incorporate the average of total lifting time, the longest of total lifting time, and the fastest of total lifting time.

To complement the table view analysis, the graphical view analysis is also presented in the following section.

6.6.8.2 Graphical View

The recorded installation time is also presented in Graphical View which allows users to analyze the recorded installation time with another perspective. Zhang Li and Xiao-lan (2004) found that the following aspects can be perceived as the advantages of presenting data in a graphical view, namely: ease of comprehension, beauty, stronger comparison, clarity, straightforwardness, continuity, diversity of presentation, interesting in interpretation, deficiency of data content, and multi-dimensionality. By using the graphical view, the relationship between two axis and the trends (patterns) over the observed objects can be obtained. These components can not be gained by using the table view. Therefore to get a comprehensive understanding about the recorded installation time, the graphical view is presented to complement the generated results from the table view.

Similar to the table view, the analysis on installation that is presented in graphical view also consists of panel based, house based, and completed house based. The objective of each graph is the same with the table view. The way in presenting the recorded installation time distinguishes between the graphical view and table view. As an illustration, an analysis on installation by graphical view based on panel type criteria is presented in **Figure 6.14** below.

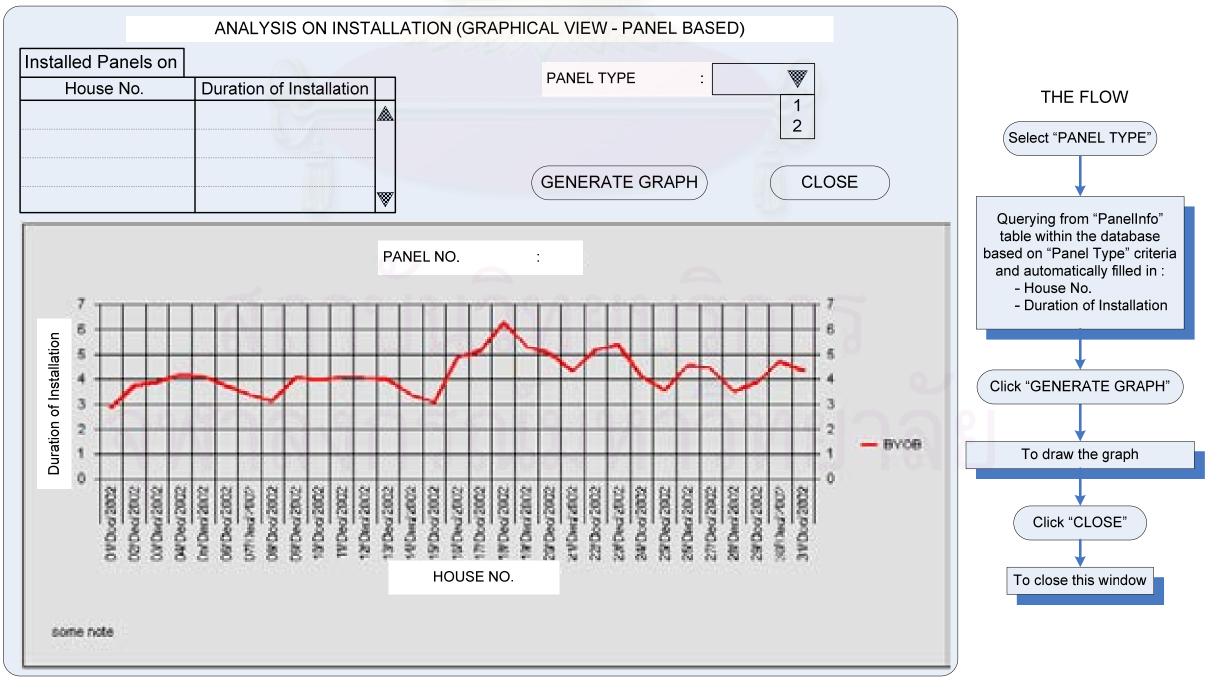


Figure 6.14 The appearance of the analysis on installation by using graphical view based on panel type criteria

As seen in **Figure 6.14** above, the graphical view consists of a table and a graph. The table provides coordinates in generating a graph. The panel based and house based utilize panel type and house number respectively as their criteria. The table displays the duration of installation. In addition, when the panel type is being the criteria then the house number will be incorporated to the displayed information and vice versa. The graph displays the criteria as the X-axis and the duration of installation as Y-axis. For the completed house based, similar to the table view, the graph puts the completed house number as X-axis and the duration of installation as Y-axis. The detail appearances of the house based and completed house based are presented in the **Appendix B13** and **B14** respectively.

6.7 The Possible Use of the Output

The RFID System has encompassed several features of output, namely: panel information, reports and analysis on installation. The reports itself consists of report of delivered panels, reports of arrived panels, and reports of installed panels. Analysis on installation has been categorized into two method of data presentation, namely: table view and graphical view. Both data presentation methods presents the information in three criteria based, namely: panel based, house based, and completed house based. The aforementioned outputs are classified into two types based on the generated information, namely: related jobsite information and feedback information (as shown in **Table 6.1** below). Their possible usage is presented afterwards.

Table 6.1 RFID System outputs and their classification based on the generated information

Source	Types of generated information		Information description
	Related Jobsite	Feedback	
Panel Installation	✓		Provides information of the current installed panels and next panel to be installed
Panel Information	✓		Provides detail information of associated panel → assist related parties in identifying and installing prefab panel
Report of Delivered Panels and Arrived Panels		✓	Allow in monitoring the quantity and quality of panels when they depart the manufacture and arrive at construction site
Report of Installed Panels		✓	Allows in monitoring the current work progress
Analysis on Installation		✓	Allows in evaluating the current performance of installation process by presenting the information in : ✓Table View → descriptive statistic (i.e., the sum, the average, the maximum, and the minimum) ✓Graphical view → reveals the patterns or the trends of the data ❖Both enable the management to analyze the current work performance, trace the problem origin, and solve the problem.

The panel information presents detail information of a particular panel that is being interrogated. The provided information includes the Panel ID, Project No., House No., Panel Type, Function, Dimension, Position (Layout), Detail Drawing, and Panel Handling. The first-four information is utilized in identifying a particular panel.

It will prevent the misplaced panel when it is stored at A-frame that has been assigned to a particular house. In addition, it will prevent the crews in lifting the wrong panel when they are performing the installation. The position, the detail drawing, and panel handling will help the crews at construction site in getting known with the panel, its components, its installation point, and its proper handling. This information can enhance the crews' learning stage so that the preparation activities and panel handling can be well performed. Conclusively, the panel information has a potency to enhance the identification of precast panel, the learning process of the crews, and the coordination among crews in performing their tasks. These benefits lead to a streamlined decision making process.

Report of Delivered Panels can be utilized to monitor the panel circulation within the manufacturer. The manufacture can utilize the report of delivered panel to optimize their inventory level along with stock yard management. In addition, the report of delivered panels can be used to monitor the panels' delivery in terms of quantity and quality. The Report of Arrived Panels can be used to monitor panels' quantity and quality upon the arrival at construction site. Together, both consecutive reports enable in cross-checking the panels' quantity and quality between the departure and arrival. The cross-checking enables the management in evaluating the panel transportation performance to tracing and solve the problems within the panel transportation. The report of arrived panels enables the management to give a quick response whenever either defected or rejected panels are found. The management will be able to issue a request order to the manufacture to send the replacements prior the installation date to prevent the under supply of precast panels.

More possible uses are generated from the Report of Installed Panels. Most of the possible uses benefit the management. The report of installed panels enables the management to monitor the current work progress. By monitoring the current work progress, the management can easily give response to the actual work progress in form of adjusting the work plan to meet their goals. The management can either accelerate or decelerate jobsite performance to achieve the best result. The decisions can be coordinated with the manufacturer to match their precast panel supply with the actual needs of construction site. The report of installed panels can be perceived as a well documented jobsite performance which can be utilized for further analysis and purposes.

The information that associated to installation event particularly the duration of installation can be further analyzed to evaluate the current performance of installation process. This information can be perceived as feedback information of precast installation process. The feedback information facilitates the management in evaluating the current performance of precast installation process, tracing the problems origins, and lastly, solving the problems towards process improvement. A simple analysis is made on the recorded installation time and presented in forms of table and graphical.

Both of presentation methods focus on the recorded installation time which based on several criteria, namely panel, house, and completed house. The panel based analysis aims to compare the installation time of a given panel at any houses. The house based analysis intends to observe the installation time of panels that form a given house. Lastly, the completed house based analysis aims to compare the total installation time of completed houses.

Both of table view and graphical view has its own advantages in presenting the data. Both are complementing one to another. The table view generates descriptive statistic to represent the data by using summary values, namely: the sum (total), the average, the maximum, and the minimum. The graphical view enables users to observe the trends or patterns of the data. By using the generated results of these two methods, the management will be able to analyze the current work performance, trace the problem origin, and solve the problem consecutively towards process improvement.

Conclusively, the generated output yields many possible uses to the involved parties. The involved parties can interpret and utilize the generated output to meet their needs in performing their work. The possible uses of the generated output offer many advantages to each involved party. A monitored delivery, an enhancement in yard management, and a fast response in production to the actual needs of construction site are the benefits to the manufacturer. A faster decision making process and a better coordination among the crews benefit the construction site crews. The management is benefited by a fast decision making process in responding to the current jobsite performance and a feedback information which enables the management to perform process improvement.

6.8 Conclusion

The RFID System is designed and generated to get an accomplishment of the conceptual model of RFID application into construction industry along with the exploration of RFID characteristics by using precast installation process as a case study. This case study aims to initiate further application of RFID into construction industry. RFID System is then proposed to support prefabrication installation process by overcoming the barriers in obtaining related jobsite information and feedback information.

Several stages are carried out in designing and developing the RFID System. It is started with the identification of the involved parties and their requirements upon information along the defined precast installation process. The identification is continued to recognize the involved parties' roles in providing and using the involved information at each of defined events, namely: departure, arrival, and installation. With regard to the identification stage's results, a framework of RFID System is proposed which involves three modules, namely: pre-input, input, and output. The framework of RFID System represents the work sequence of precast installation process.

By using the proposed framework, the designing and development of RFID System is commenced. The first part of RFID System which is the main menu incorporated seven of 1st level menus, namely: Define Panel Type, Quantity & Quality Checking, Panel Installation, Panel Information, Reports, Analysis on Installation, and Exit menus. The first menu and the second two menus are considered as pre-input and input modules respectively. The rest of the menus are perceived as the output. The pre-input and input modules are addressed to collect associated information to panel detail information and three events (i.e., departure, arrival, and installation) respectively. The output module incorporates panel information, reports and analysis on installation. The reports are presented separately based on the three events. By using the associated information to the installation event, a simple analysis is made and presented into two methods, namely table view and graphical view. Both table and graphical views focus on three objects based, namely: panel based, house based, and completed house based.

Each of the output yields possible uses to the involved parties. The Panel Information is utilized to provide detail information of a particular panel which can enhance the identification of precast panel, the learning process of the crews, and the coordination among crews in performing their tasks. The report of delivered panels can be used by the manufacturer to monitor the panel delivery in terms of quantity and quality and perform inventory and stockyard management. The report of arrived panels can be used to monitor panel's quantity and quality upon the arrival at construction site. Together, both consecutive reports enable in cross-checking the panel's quantity and quality between the departure and arrival to evaluate the transportation process. The table and graphical views of analysis on installation enable the management to analyze the current work performance by investigating with the summary values and the graph patterns, trace the problem origin, and solve the problem consecutively towards process improvement.

The possible uses of the generated output offer many advantages to each involved party. A monitored delivery, an enhancement in yard management, and a fast response in production to the actual needs of construction site are the benefits to the manufacturer. A faster decision making process and a better coordination among the crews benefit the construction site crews. The management is benefited by a fast decision making process in responding to the current jobsite performance and a feedback information which enables the management to perform process improvement.

Conclusively, RFID System incorporates three modules, namely: pre-input, input, and output to overcome the barriers in obtaining related jobsite information and feedback information. The information that is collected either at pre-input and input stages is stored within the database and presented afterwards whenever it is required in form of "Panel Information, "Reports", and "Analysis on Installation". By providing related jobsite information and feedback information, the possible uses of RFID System's output show the importance of the information towards process improvement.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

The conclusions upon the research and the findings and some recommendations are presented within this chapter. After determining the research objective, subsequent stages were performed in achieving the research objective. Each of the stages generated results which can be perceived as findings. The conclusions upon the findings and the recommendations are presented consecutively.

7.1 The Research

This research is aimed at applying RFID as the cutting edge of automatic identification technologies together with the database as one of many ITs applications for process improvement. Prefabrication installation in housing project is selected to be a case study within this research. The RFID and the database are utilized in obtaining feedback information and providing related jobsite information which both types of information are believed as the essential components for process improvement.

Therefore, in achieving the defined objective, the research was conducted through several stages. The research was initiated by reviewing related literatures and conducting field observations. Considered as preliminary researches, these initial studies are utilized as a basis in constructing the conceptual model of RFID application in precast installation process. The conceptual model is then realized by exploring the RFID characteristics and the designing and developing the RFID system afterwards. Conclusions and recommendations based upon the findings are made and presented as an end of the research. The generated findings of each of the stages are presented in the following section.

7.2 The Findings

As resulted from the literature review, process becomes the key in achieving higher productivity. A higher productivity can be achieved by looking into the process, evaluating the current process to gain feedback and conducting a continuous process improvement. Process improvement is found as a method of productivity improvement given from the facts that it improves information flow, minimizes waste of labor hour, and reduces productivity loss.

However, the process improvement entails feedback information and related jobsite information along the process. Feedback information is useful in identifying the problem origin and determining corrective action. Whereas related jobsite information is very helpful to streamline the decision making process if it is processed and delivered in a timely and accurate manner.

As generated from the field observation, the precast installation process is currently experiencing barriers in obtaining those two types of information to improve its process. The precast installation process has realized the importance of these types of information. The availability and time consuming tasks in capturing and storing the information about the current practice of precast installation process have impeded efforts towards process improvement. In addition, the out of date, untimely, and inaccurate related jobsite information has become barriers in commencing the works and decision making process.

Therefore, improvements upon precast installation process can be made by providing these two types of information. ITs (information technologies) have been observed as promising solution to overcome those information barriers. Information technologies (ITs), by providing faster feedback and accurate information and supporting for remote and concurrent decision making, offered the possibility to improve precast installation process.

Thus an information system which is comprised of the use of radio frequency identification (RFID) as an automated identification tool integrated with a database is proposed to support the precast installation process. RFID system is utilized in obtaining feedback information and providing related jobsite information that can be used for process improvement. How the RFID System will be implemented into precast installation process? It is illustrated within the conceptual model of RFID application in precast installation process which is presented in the following section.

7.2.1 Conceptual Model of RFID Application in Prefabrication Installation Process

The conceptual model of RFID application in precast installation process aims to describe one from many applications of RFID in construction industry. A new information system makes use of radio frequency identification (RFID) as an automated identification tool integrated with a database is proposed. This new system aims to support precast installation process by providing related jobsite information to enhance the decision making process and provide feedback information that can be used for further analysis for process improvement. Both types of information are very valuable to streamline the process. Within precast installation process, the RFID system is implemented into two phases. The first phase stretches from manufacture to precast stockyard; the second phase stretches from precast stockyard to installation point. The RFID system automatically identifies prefabrication (precast) panels, collects and records their related data (work sequences, panels handling, and installation time) to a database, and monitors the status (real time) of jobsite performances.

Information from the RFID system and generated reports can be used for many purposes. Different users utilize different information and are benefited differently. The RFID system assists the manufacturer, management and engineer/foreman in doing their works. For manufacturer, information from generated reports determines which panels have to be produced and delivered to reduce the risk of inventory shortage. For the management, information from the generated reports helps to monitor the work progress whether it is on time or behind schedule. Management makes use of the RFID system to record the installation activities and evaluate its performance to identify the problem origins and determine corrective actions. For the foreman and crane operator, the information from the RFID system helps them to enhance coordination in executing the work and increases their learning. The proposed conceptual method of RFID application in prefabrication installation process can be fully accomplished by proposing the best usage of RFID and developing the RFID system. The best usage of RFID is explored within the exploration of RFID characteristic which is presented in the following section.

7.2.2 The Exploration of RFID Characteristics

Lack of knowledge on RFID characteristics has become an impeding factor for its applications in construction industry. Therefore, through the Exploration of RFID Characteristics, the characteristics of RFID are explored to its limits. In addition, several simulations are conducted to meet the needs of RFID application to precast installation process. General characteristics are identified and unique characteristics are presented as guidelines in implementing RFID to meet the needs of the proposed application.

The characteristics of RFID are investigated in two stages. The first stage investigated the RFID characteristics for the general usage. Whereas at the second stage, simulations of the on-site precast panels' arrangement are carried out to find the best usage of RFID application in precast installation process. The first investigation encompassed the readable coverage areas of the RFID tags, the reliability, maximum number of detected tags, and minimum distance between tags that can be read separately. The second stage aims to investigate the behaviors of RFID when it is applied to precast installation process to meet the needs of the proposed RFID application.

General findings shows that the tag orientations, tag positions, distance, and interrogation angle, the presence of other tags (interference) affect the RFID performance. Vertically oriented tag performs more superiorly than horizontal. Some of the characteristics such as reading rate, the maximum amount of detected tags at once, and the minimum spacing distance between tags tend to decrease their performances as the reading distance increases. The center position has a better performance than any other positions. The coverage area tends to be smaller whenever the reader rotates either horizontally and vertically. Furthermore, the unique findings create a corridor in implementing RFID. To get a proper use of RFID, the working area should comply with the unique characteristics. The RFID performance itself is also affected by many factors instead of its properties.

As generated from the simulations, a recommendation upon the best usage of RFID to meet the needs of proposed RFID application in precast installation process has been made. Within the proposed RFID application, only the selected panel will respond when the reader interrogates the panels. Therefore, the findings lead to the usage of the 1st and 3rd combinations of placing three precast panels in A-frame with the working distance ranges from 1.80 m to 1.92 from the side of the associated panel. Note that the reader should be rotated 30 ^{o} incline upwards and downwards depending on the associated tag position on the panel.

7.2.3 The Design and the Development of RFID System

As previously mentioned, the precast installation process is currently experiencing barriers in obtaining the two types of information to improve its process. A system that can obtain feedback information and provide related jobsite information towards process improvement is essentially required. Therefore, RFID System is proposed to support prefabrication installation process by overcoming the barriers in obtaining those types of information.

Several stages are carried out in designing and developing the RFID System. It is started with the identification of the involved parties and their requirements upon information along the defined precast installation process. The identification is continued to recognize the involved parties' roles in providing and using the involved information at each of defined events, namely: departure, arrival, and installation. With regard to the identification stage's results, a framework of RFID System is proposed which involves three modules, namely: pre-input, input, and output. The framework of RFID System represents the work sequence of precast installation process.

By using the proposed framework, the designing and generating of RFID System is commenced. The first part of RFID System which is the main menu incorporated seven of 1st level menus, namely: Define Panel Type, Quantity & Quality Checking, Panel Installation, Panel Information, Reports, Analysis on Installation, and Exit menus. The first menu and the second two menus are considered as pre-input and input modules respectively. The rest of the menus are perceived as the output. The pre-input and input modules are addressed to collect associated information to panel detail information and three events (i.e., departure, arrival, and installation) respectively. The output module incorporates panel information, reports and analysis on installation. The reports are presented separately based on the three events. By using the associated information to the installation event, a simple analysis is made and presented into two methods, namely table view and graphical view. Both table and graphical views focus on three objects based, namely: panel based, house based, and completed house based.

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7.3 Limitations

The generated findings that are presented within this research need to be verified for the general applications due to several limitations. These limitations have occurred as the result of the selections upon the media, the equipment (i.e., RFID tag and reader), and the precast arrangement. The details of these limitations are presented as follows:

a. The Selection upon Media

The Styrofoam was selected as a testing media within this research because of its neutrality. It does not absorb the Radio Frequency (RF) wave as much as other materials do. The preliminary investigations generated that various materials adsorb the RF wave differently. Brick walls and metals do absorb the radio wave since both materials yield very short reading distances, ranging from 0.5 m to less than 1.6 m. The light weight wall made from gypsum material yields maximum reading distance up to 2.29 m. Styrofoam yields 2.4 m as maximum reading distance, therefore it was selected as the test material. Note that the reading distance is measured based on horizontally oriented tags.

The selection on Styrofoam as media has raised a query upon the findings' validity when the RFID is applied into the real precast installation process. The current practice of precast installation process utilizes concrete panels as the media. Based on the preliminary investigations, the concrete panel adsorbs the RF wave and generates a shorter reading range. The reading range is vary depends on the concrete panel's materials mixture.

The use of concrete panels as media will generally result the similar RFID characteristics as resulted from the use of Styrofoam. Obviously, the RFID characteristics that are presented in reading range will be shorter than the resulted from the Styrofoam. The proposed interrogating method might not be the suitable one when the media is replaced by concrete panel. Therefore further investigations of RFID characteristics on the concrete panels need to be conducted.

b. The Selection upon Equipment

This research selected a particular RFID reader and tag among various readers and tags that can be found in the current market. The use of different readers and tags might yield different reading range which can be longer or even shorter than the generated findings. The RFID characteristics will be generally the same regardless of using different reader and tag. The generated findings will not be fully valid if different reader and tag take place. Therefore, further investigations of RFID characteristics upon the different reader and tag need to be carried out.

c. The Selection upon Precast Arrangement

The precast arrangement that was utilized within this research is just a part of various precast arrangements in precast installation process. The proposed best usage of RFID application in precast installation process might not be valid if it is implemented in other precast arrangements. Therefore, it is suggested to perform further investigations upon a particular precast arrangement that is selected to be implemented in precast installation process to find the best usage of RFID application.

7.4 Recommendations

In regard to the aforementioned findings, recommendations can be made upon the application of RFID for construction process improvement particularly in precast installation process. Recommendations are addressed to several issues, namely: the scope of the observed process, the code usage and data storage, and the usage of

RFID. The detail recommendation on these issues is presented in the following section.

The limited scope of the observed process within this research may cause the partial benefits of the RFID application for construction process improvement. The current involved process within precast installation process is expected to initiate of more comprehensive studies. For instance, the recorded installation time is limited to the precast panel lifting stage. The precast panel lifting stage is a part of the precast installation process. The partial measurement yields a partial analysis of precast installation process. If the execution time of whole precast installation process can be captured, comprehensive studies upon the captured time enables the comprehensive work study to be carried out. The captured time allows the work study to investigate another partial process in precast installation process. Conclusively, there will be two kind of work study can be carried out by using the fully captured time of precast installation process. Obviously, comprehensive work study of the overall work tasks within precast installation process can be performed. In addition, a partial work study of the other work tasks also can be performed. A partial improvement may leads to a greater improvement upon the precast installation process. Analogically to the expanding scope at work task level of precast installation process, it is recommended to involve other processes within precast construction project.

Lastly, to achieve the best usage of RFID application in construction industry, it is essential to recognize the RFID characteristics prior to the implementation of RFID on construction site. The RFID performances are affected by many factors. The tag orientations, tag positions, distance, and interrogation angle, and the presence of other tags (interference) just some parts of RFID characteristics that have been revealed within this research. The environments also have a major impact to the RFID performance. RFID performance is affected by electrical noise and interference that may be present in the environment. It is essential to understand the fundamental properties of radio wave such as reflection, refraction, diffraction, and multipath. Given to the interaction between the characteristics of RFID itself and the environment, it is recommended to explore the RFID characteristics by performing a series of tests and simulating the proposed application before going further into applying RFID for the construction industry. Then, the practical use of RFID in the proposed application should comply with the findings to get the best usage of RFID.

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APPENDICES

APPENDIX A

THE EXPLORATION OF RFID CHARACTERISTICS

A1. The Collected Data of the Maximum Amount of Detected Tags at Once

Distance (m)	Position on panel	Amount of detected tags	
		Horizontally oriented	Vertically oriented
0.5	Upper	6	2
	Center	10	20
	Lower	7	0
1.0	Upper	1	2
	Center	8	19
	Lower	4	2
1.5	Upper	1	2
	Center	4	10
	Lower	2	4
2.0	Upper	1	2
	Center	4	7
	Lower	2	5
2.4	Upper	0	2
	Center	0	4
	Lower	0	2

A2. The Collected Data of the Minimum Distance (Spacing) between Tags to be Read Separately

Distance (m)	Position on panel	Minimum spacing distance between tags that can still be read separately (m)	
		Horizontally oriented	Vertically oriented
0.5	Upper	1.4	1.2
	Center	2.0	3.4
	Lower	1.0	1.4
1.0	Upper	1.8	1.2
	Center	1.6	3.2
	Lower	2.2	0.8
1.5	Upper	0.6	2.4
	Center	1.6	2.2
	Lower	1.6	1.8
2.0	Upper	1.2	1.0
	Center	1.2	1.2
	Lower	1.8	0.6
2.4	Upper	1.4	1.0
	Center	0.6	1.6
	Lower	1.4	0.8

A3. The Collected Data of the Simulation of Placing 1 Precast Panel on A-frame

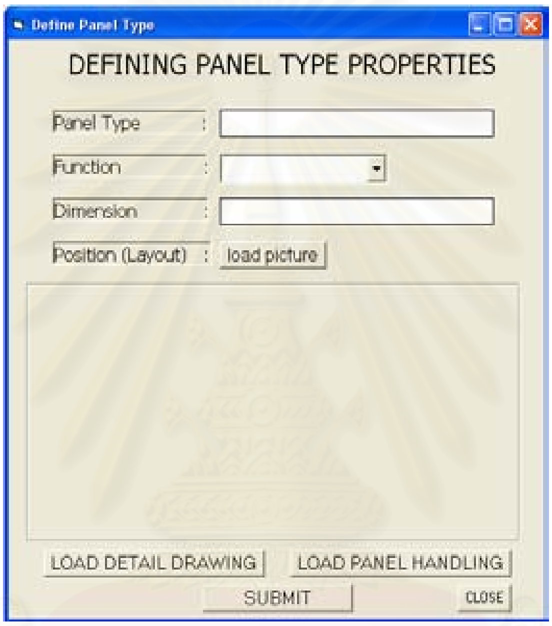
		Maximum reading distance(m)	
Position on panel	Reading Direction	Horizontally oriented	Vertically oriented
Upper	Front	1.55	2.60
	Angle 45^{o}	1.58	2.48
	Side	1.60	2.60
Middle	Front	2.33	3.26
	Angle 45^{o}	2.01	3.94
	Side	0.49	2.00
Lower	Front	2.23	2.58
	Angle 45^{o}	1.93	2.44
	Side	1.20	0.40

APPENDIX B

THE DESIGN AND THE DEVELOPMENT OF RFID SYSTEM

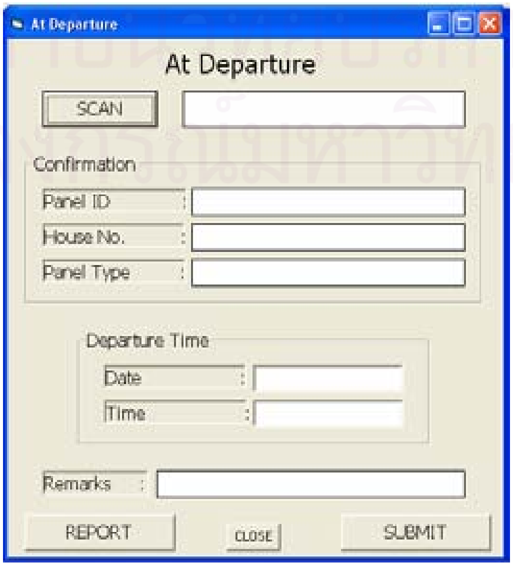
B1. The Appearance of the Define Panel Type Form

The Generated Define Panel Type Form



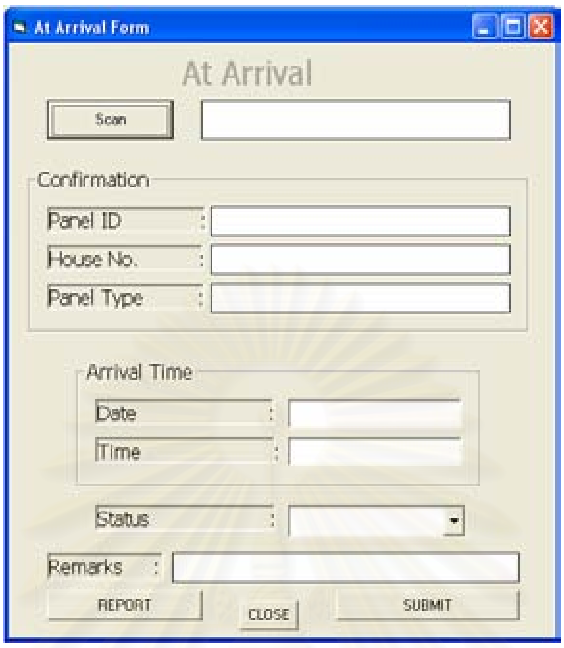
B2. The Appearance of the At Departure Form

The Generated At Departure Form



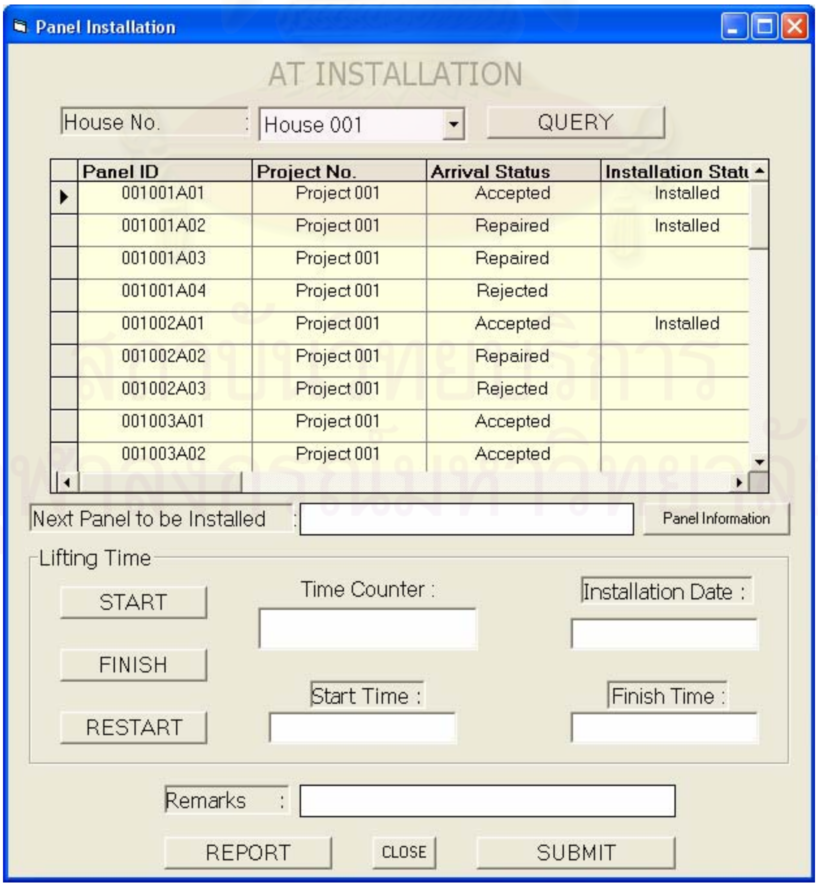
B3. The Appearance of the At Arrival Form

The Generated At Arrival Form



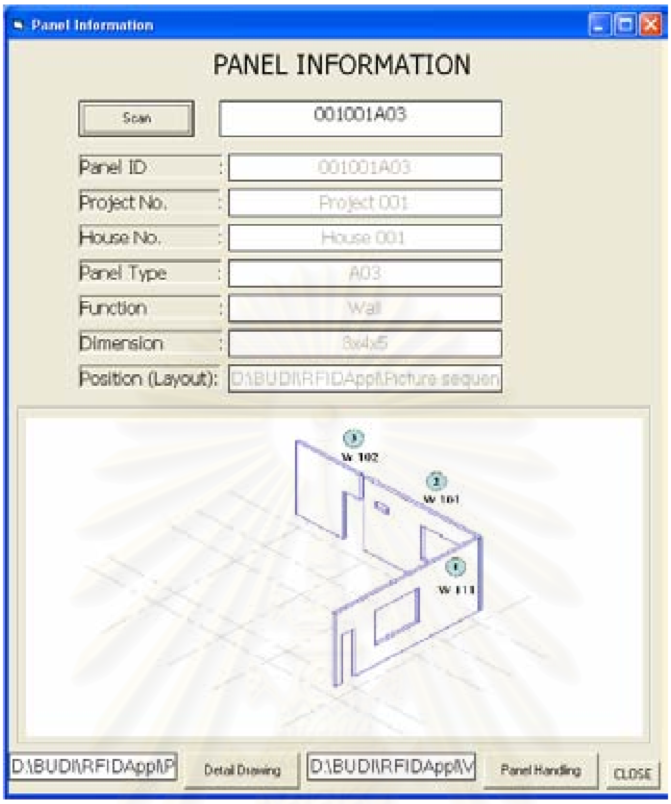
B4. The Appearance of the At Installation Form

The Generated At Installation Form



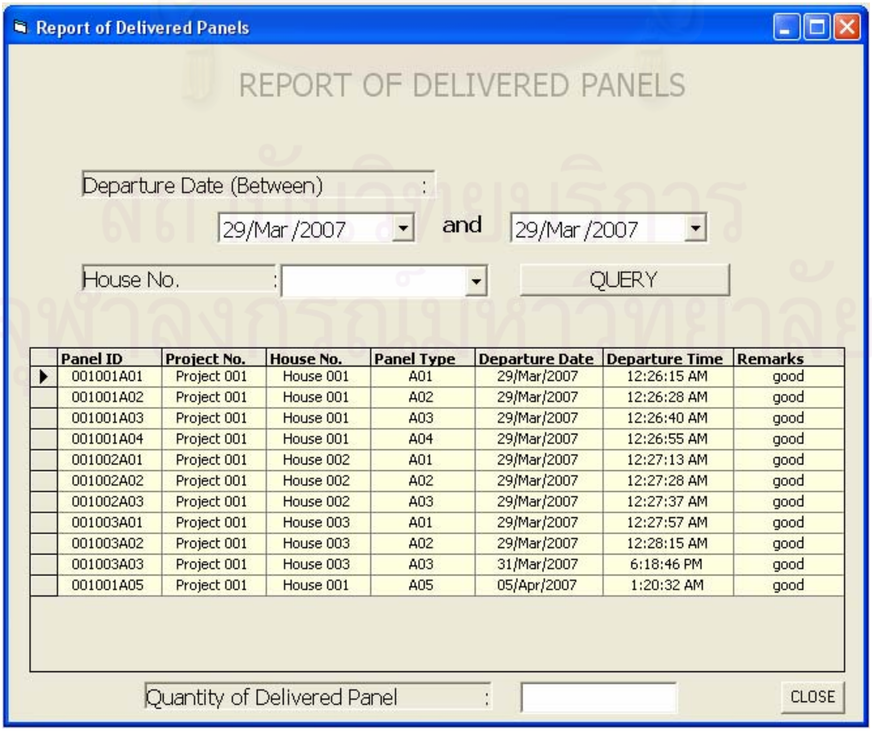
B5. The Appearance of the Panel Information Form

The Generated Panel Information



B6. The Appearance of the Report of Delivered Panels

The Generated Report of Delivered Panels



Report of Delivered Panels

REPORT OF DELIVERED PANELS

Departure Date (Between) :

29/Mar /2007 and 29/Mar /2007

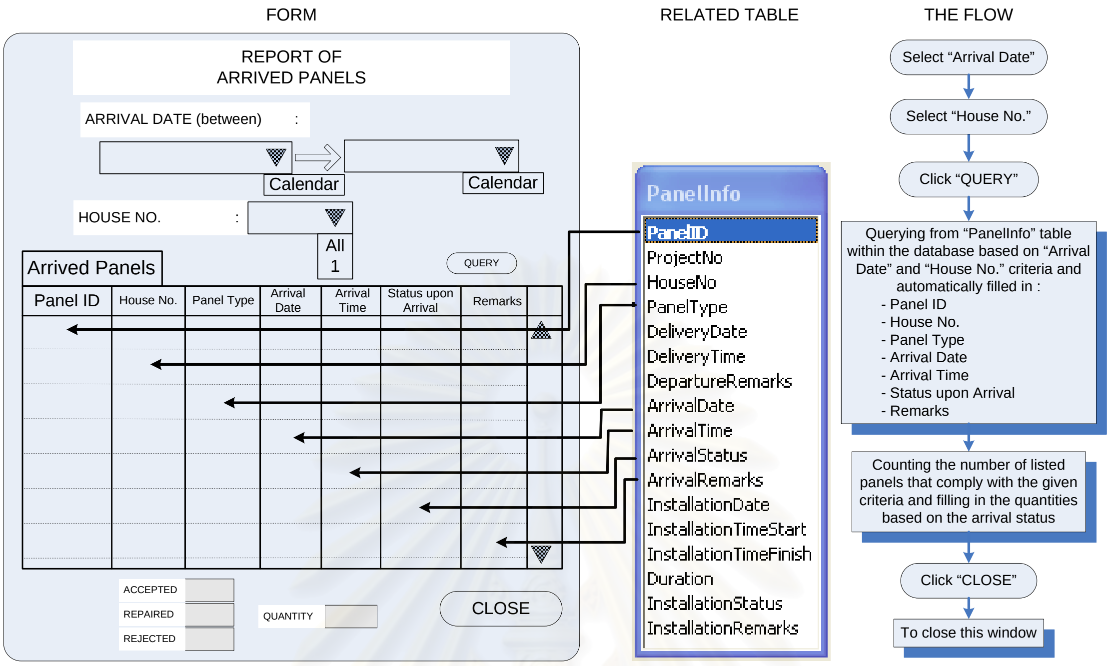
House No. : QUERY

Panel ID	Project No.	House No.	Panel Type	Departure Date	Departure Time	Remarks
001001A01	Project 001	House 001	A01	29/Mar/2007	12:26:15 AM	good
001001A02	Project 001	House 001	A02	29/Mar/2007	12:26:28 AM	good
001001A03	Project 001	House 001	A03	29/Mar/2007	12:26:40 AM	good
001001A04	Project 001	House 001	A04	29/Mar/2007	12:26:55 AM	good
001002A01	Project 001	House 002	A01	29/Mar/2007	12:27:13 AM	good
001002A02	Project 001	House 002	A02	29/Mar/2007	12:27:28 AM	good
001002A03	Project 001	House 002	A03	29/Mar/2007	12:27:37 AM	good
001003A01	Project 001	House 003	A01	29/Mar/2007	12:27:57 AM	good
001003A02	Project 001	House 003	A02	29/Mar/2007	12:28:15 AM	good
001003A03	Project 001	House 003	A03	31/Mar/2007	6:18:46 PM	good
001001A05	Project 001	House 001	A05	05/Apr/2007	1:20:32 AM	good

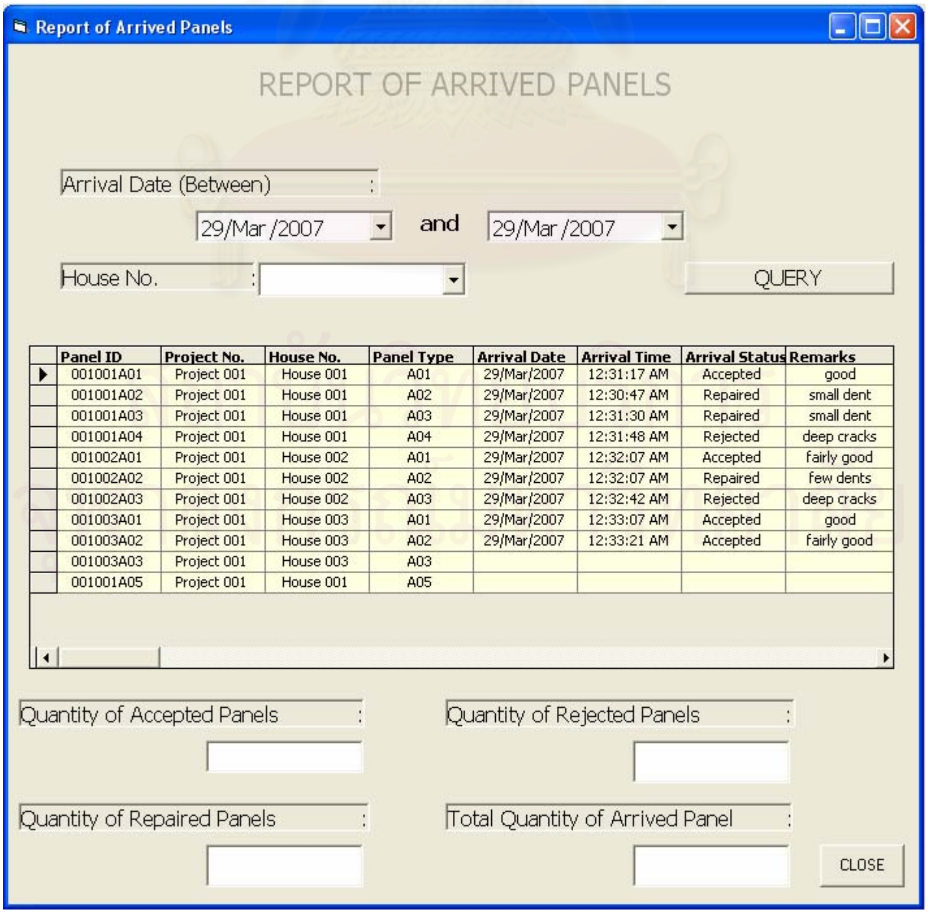
Quantity of Delivered Panel : CLOSE

B7. The Appearance of the Report of Arrived Panels

The Design of Report of Arrived Panels



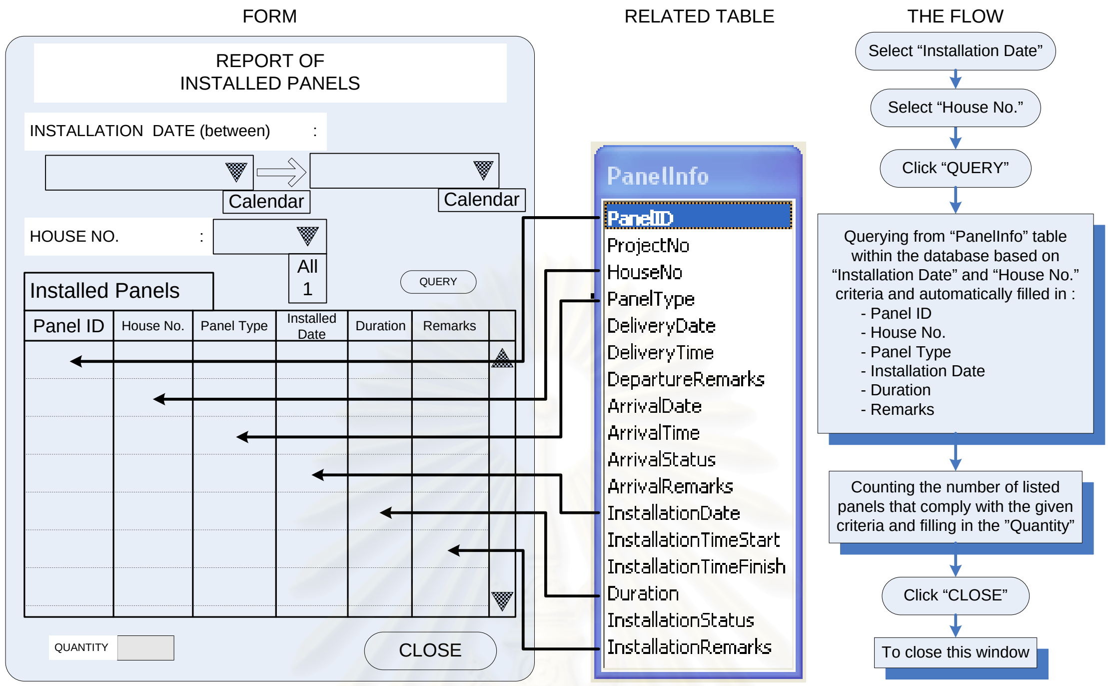
The Generated Report of Arrived Panels



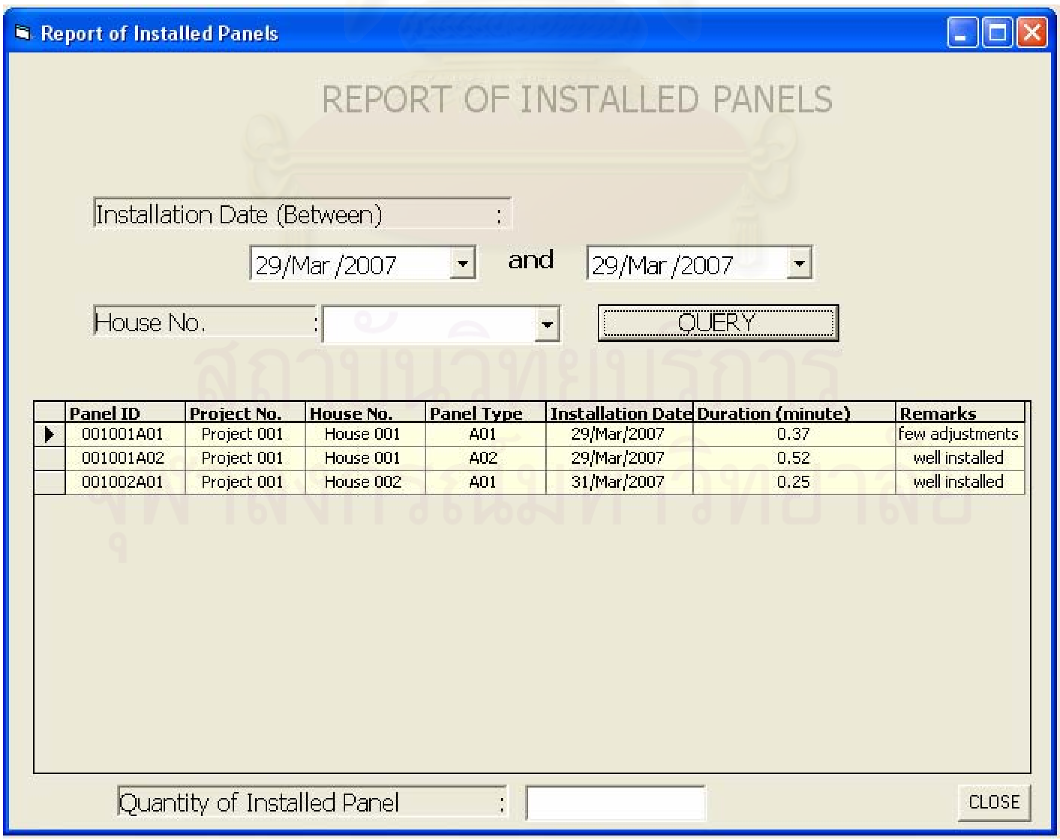
Panel ID	Project No.	House No.	Panel Type	Arrival Date	Arrival Time	Arrival Status	Remarks
001001A01	Project 001	House 001	A01	29/Mar/2007	12:31:17 AM	Accepted	good
001001A02	Project 001	House 001	A02	29/Mar/2007	12:30:47 AM	Repaired	small dent
001001A03	Project 001	House 001	A03	29/Mar/2007	12:31:30 AM	Repaired	small dent
001001A04	Project 001	House 001	A04	29/Mar/2007	12:31:48 AM	Rejected	deep cracks
001002A01	Project 001	House 002	A01	29/Mar/2007	12:32:07 AM	Accepted	fairly good
001002A02	Project 001	House 002	A02	29/Mar/2007	12:32:07 AM	Repaired	few dents
001002A03	Project 001	House 002	A03	29/Mar/2007	12:32:42 AM	Rejected	deep cracks
001003A01	Project 001	House 003	A01	29/Mar/2007	12:33:07 AM	Accepted	good
001003A02	Project 001	House 003	A02	29/Mar/2007	12:33:21 AM	Accepted	fairly good
001003A03	Project 001	House 003	A03				
001001A05	Project 001	House 001	A05				

B8. The Appearance of the Report of Installed Panels

The Design of Report of Installed Panels

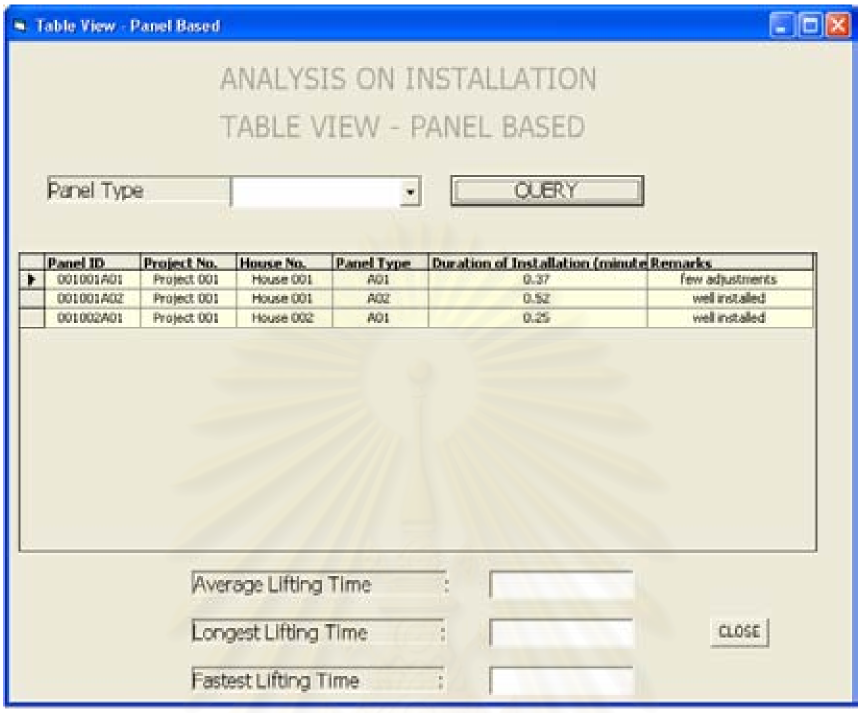


The Generated Report of Installed Panels



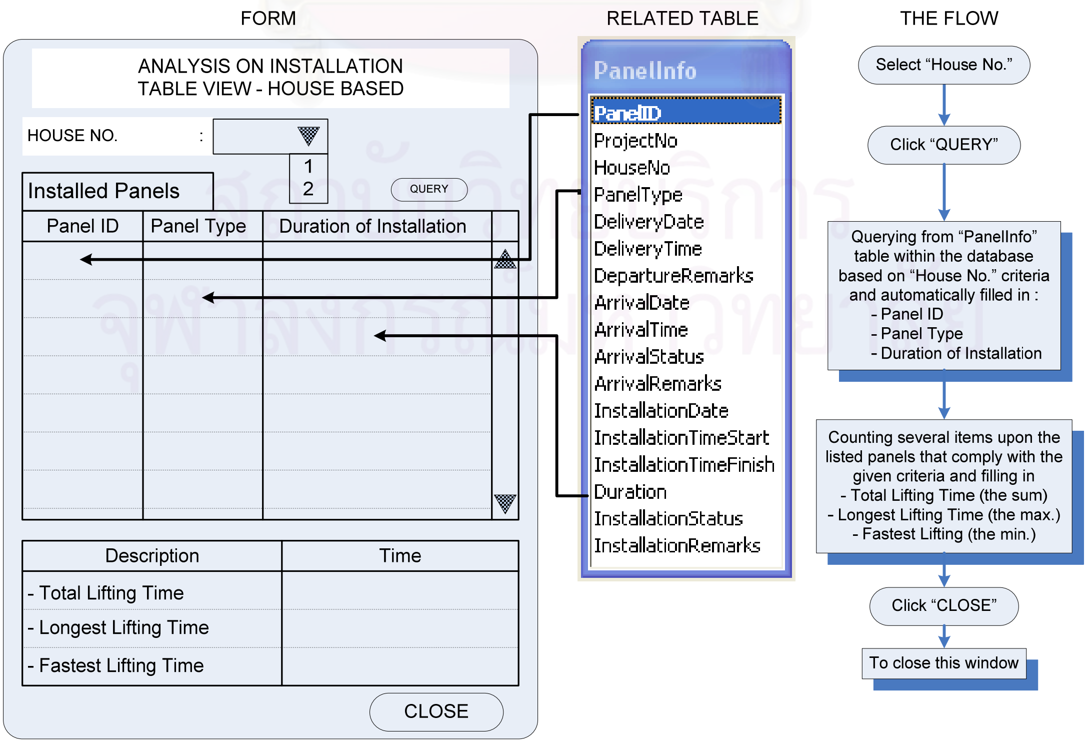
B9. The Appearance of the Analysis on Installation by using Table View based on Panel Type Criteria

The Generated Table View of Panel Type (An Analysis on Installation)

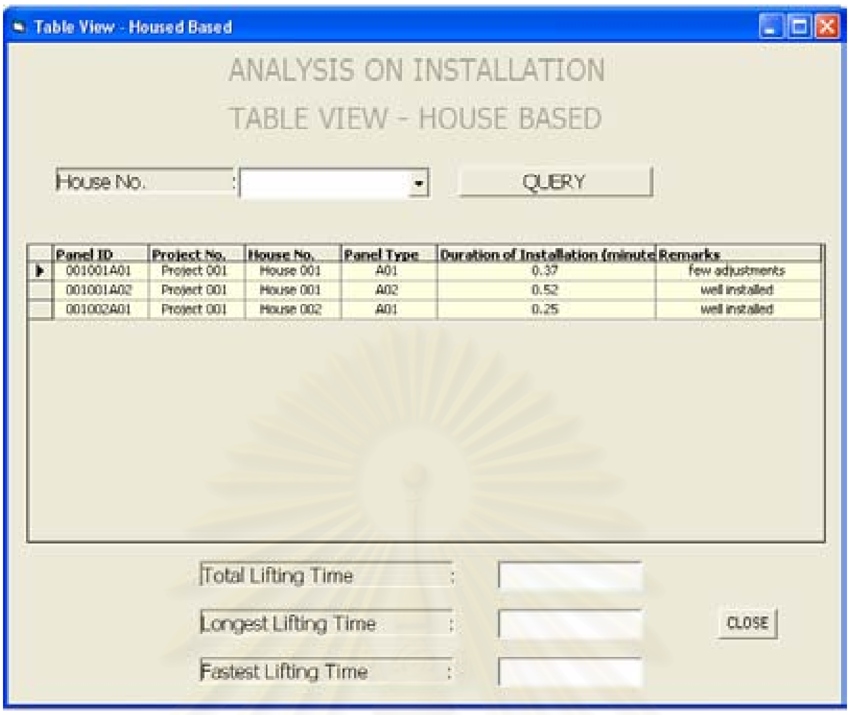


B10. The Appearance of the Analysis on Installation by using Table View based on House Number Criteria

The Design of Table View of House Number (An Analysis on Installation)

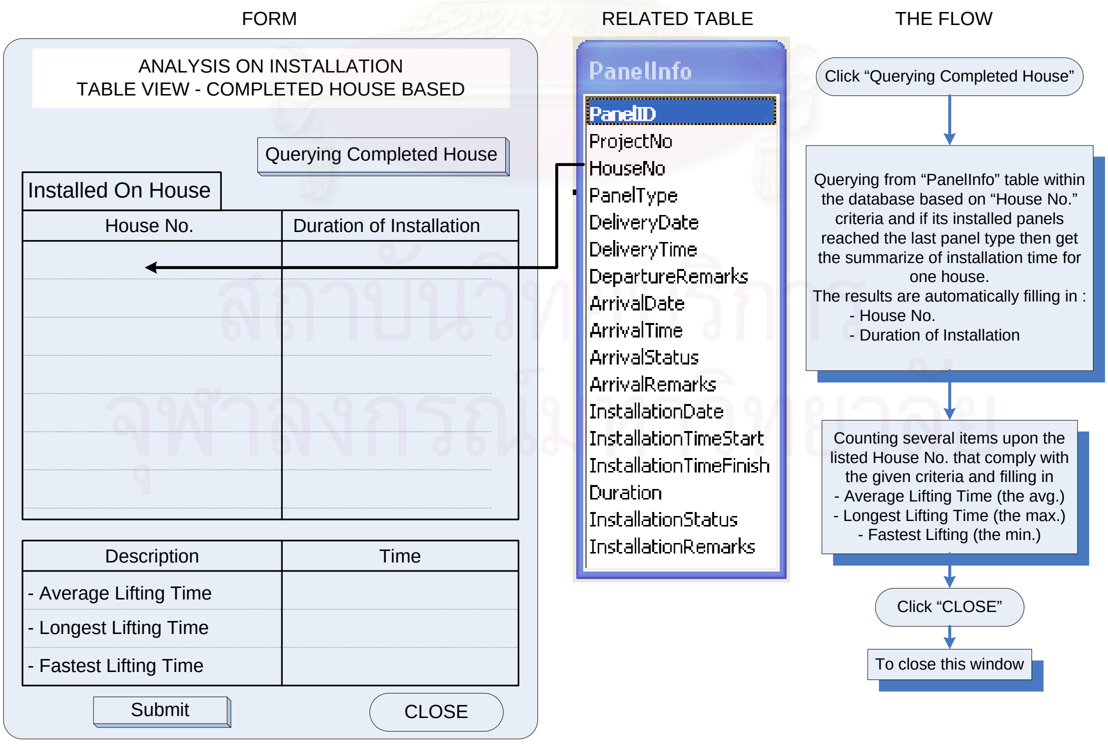


The Generated of Table View of House Number (An Analysis on Installation)



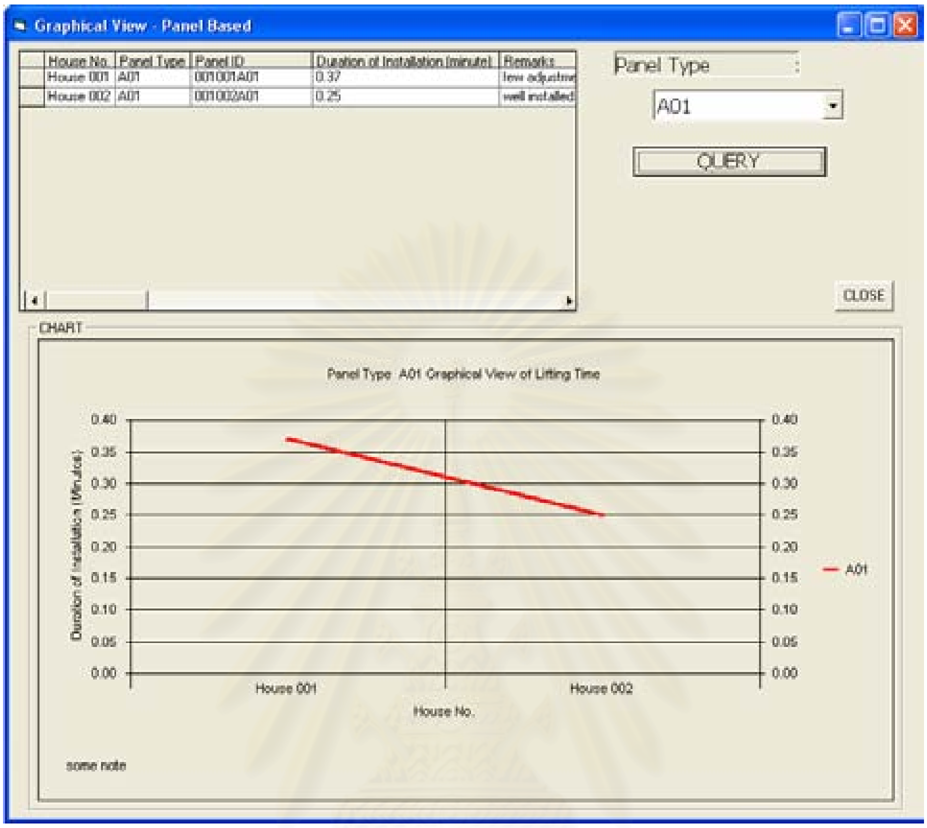
B11. The Appearance of the Analysis on Installation by using Table View based on Completed House Criteria

The Design of Table View of Completed House (An Analysis on Installation)



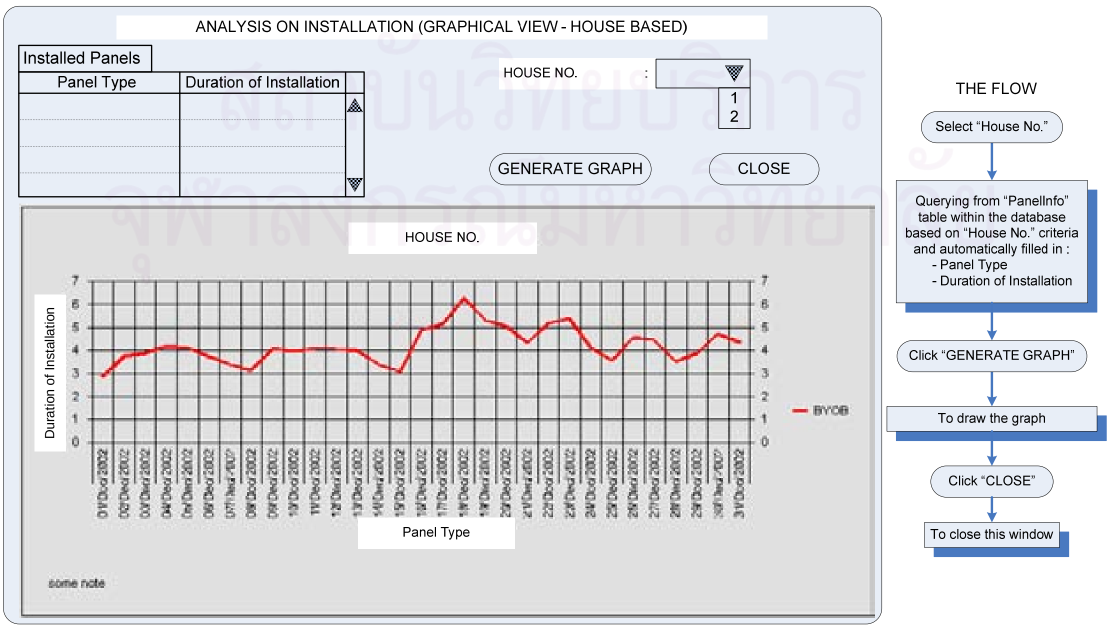
B12. The Appearance of the Analysis on Installation by using Graphical View based on Panel Type Criteria

The Generated Graphical View of Panel Type (An Analysis on Installation)

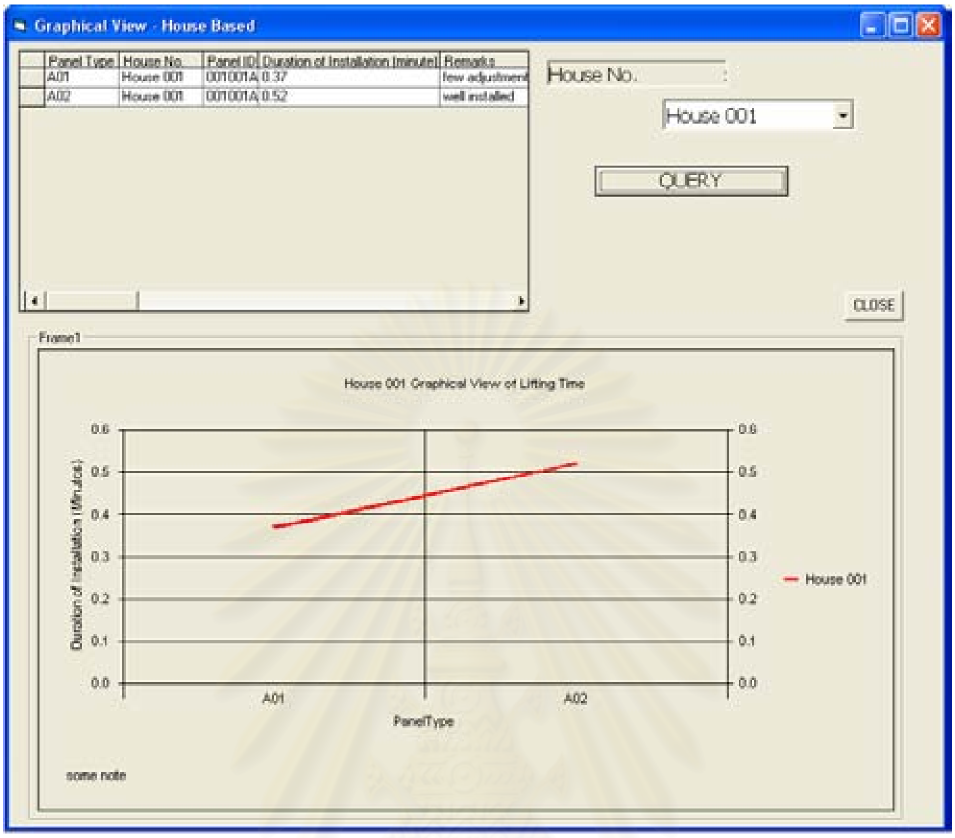


B13. The Appearance of the Analysis on Installation by using Graphical View based on House Number Criteria

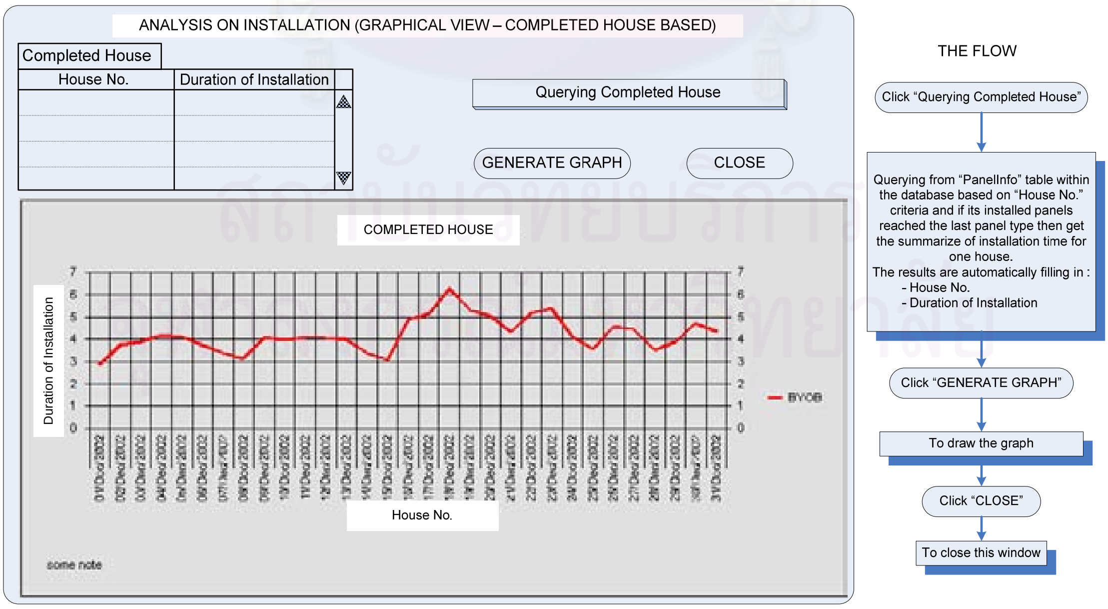
The Design of Graphical View of House Number (An Analysis on Installation)



The Generated of Graphical View of House Number (An Analysis on Installation)



B14. The Appearance of the Analysis on Installation by using Graphical View based on Completed House Criteria



LIST OF PUBLICATIONS

V. Peansupap, T. Tongthong, and B. Hasiholan. Conceptual Model of RFID Application in Prefabrication Installation Process. *5^{th} ICCPM/ 2^{nd} ICCEM 2007*, 2^{nd} – 3 rd of March 2007, Singapore.

V. Peansupap, T. Tongthong, and B. Hasiholan. The Exploration of RFID Characteristics for Using in Construction Projects. *NCCE12*, 2^{nd} – 4^{th} of May 2007, Phitsanulok, Thailand.

BIOGRAPHY

Budi Hasiholan was born in 1982 in Medan, a capital city of North Sumatera province, Indonesia. When he was five years old, he moved out to Bandung, a capital city of West Java province, Indonesia. He spent most of his time in Bandung until he finished his undergraduate study. He studied in Department of Civil Engineering, Faculty of Engineering, Insitut Teknologi Bandung (ITB), Bandung, Indonesia. He earned his Bachelor of Engineering degree in 2004. He was awarded AUN/SEED-Net scholarship to continue his study in Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand in 2005. His research interest is in Information Technologies (ITs) for construction process improvement.