LOCATING AND TRACKING ASSETS USING RFID

A Thesis

by

GAK GYU KIM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2007

Major Subject: Industrial Engineering

LOCATING AND TRACKING ASSETS USING RFID

A Thesis

by

GAK GYU KIM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Chair of Committee,	Gary M. Gaukler
Committee Members,	Lewis Ntaimo
	Yoonsuck Choe
Head of Department,	Brett A. Peters

August 2007

Major Subject: Industrial Engineering

ABSTRACT

Locating and Tracking Assets Using RFID. (August 2007)

Gak Gyu Kim, B.E., Korea Military Academy

Chair of Advisory Committee: Dr. Gary M. Gaukler

Being able to quickly locate equipment is critical inside buildings, including hospitals, manufacturing floors and warehouses. In order to utilize limited budget and resources efficiently, accurate locating or tracking is required in many fields. In this research, we will focus on how to find the location of an item by using RFID in real time indoors to track equipment.

When an item needs to be located, the purpose of using RFID is to minimize the searching time, effort, and investment cost. Thus, this research presents a mathematical model of using RFID (both handheld readers and stationary readers) for efficient asset location. We derive the expected cost of locating RFID-tagged objects in a multi-area environment where hand-held RF readers are used. We then discuss where to deploy stationary RF readers in order to maximize the efficiency of the search process.

To My Country and My Family

ACKNOWLEDGMENTS

I must first express my gratitude towards my advisor, Professor Gary M. Gaukler. I have been extremely lucky to work with him. He has always blown me away with his vision, consideration, knowledge, and cheers. I have learned many things from him. I would also like to thank my committee members, Professor Lewis Ntaimo and Professor Yoonsuck Choe, for their consideration and encouragement. They were eager to help me whenever I needed their help and advice.

I also owe very much my friends, Eunshin byon, Young-Myoung Go and Chiwoo Park. They always helped and encouraged me whenever I went through hard times during my master's degree. I would be remiss without mentioning the Korea Military Academy alumni, whose enormous generosity will be remembered always. I also would like to acknowledge my friends and colleagues at the Department of Industrial & Systems Engineering, Texas A&M University who cheered me up all the time.

Finally, I would like to thank my family who has made tremendous sacrifices to ensure that I have had a good circumstance. For this and much more, I am forever in their debt. Especially, I am extremely grateful to my lovely wife, Yumi. In spite of having to study harder to pass the bar, she always has given me happiness and confidence. Her love, sacrifice, and prayers made this research possible. My father in Heaven, I really love you.

TABLE OF CONTENTS

CHAPTER Page

CHAPTER Page

LIST OF TABLES

TABLE Page

LIST OF FIGURES

FIGURE Page

FIGURE Page

CHAPTER I

INTRODUCTION

RFID has been getting attention from many industries in recent years. However, RFID technology is not a new technology, it has been used since 1948 [1]. The Department of Defense (DoD) and market leaders such as Wal-Mart, Pfizer, Tesco, and Gillette's require their suppliers to have RFID compatibility [2]. The Food and Drug Administration (FDA) recommends the pharmaceutical companies use of RFID to prevent counterfeiting drugs [3]. Animal breeders manage their risks by tracking domestic animals' disease histories [4]. Furthermore, international harbor companies try to track in and out shipping records for security purposes. Lastly, applying RFID technology into tracking highly valued medical equipment in hospitals is predicted to increase the efficiency of managing the property [5].

In this research, we will focus on how to find the location of an item by using RFID in real time indoors to track equipment. Being able to quickly locate equipment is critical in many environments, including hospitals, manufacturing floors and warehouses. This paper presents a mathematical model of using RFID for efficient asset location. We derive the expected cost of locating RFID-tagged objects in a multi-area environment where hand-held RF readers are used. We then discuss where to deploy stationary RF readers in order to maximize the efficiency of the search process.

Object location technologies include network sensors, GPS (Global Positioning System), and ultrasonic. These technologies use methods to determine location after

---

This thesis follows the style of *IEEE Transactions on Automatic Control.*

synthesizing and analyzing various information received from their equipment. GPS [6], which is a navigation system made up of a constellation of more than two dozen satellites, transmits signal information to earth. Its receivers take this information and compares the time a signal was transmitted by a satellite with the time it was received. This time difference determines the objective location. But, GPS has limitations detecting the satellite signals inside buildings [7]. Active Bat System [8], which determines the location using triangulation, uses ultrasonic. Short ultrasonic pulse is transmitted from the transmitter, which is attached to a location-detecting-object, to the receiver which is on the wall. A detector measures the traveling time of pulse to calculate the distance between transmitter and receiver. However, it requires both advanced technology and high costs to increase the accuracy and efficiency of this system [7].

Unlike these technologies, RFID can be applied to indoor asset tracking easily. Because if the missing object is tagged, it can be found using the information from its RFID tag. In other words, RFID is able to identify tagged objects or people in the electromagnetic field. Thus, RFID can help us find missing items in hospitals, goods in warehouses, or shipments in loading docks.

Our main goal is to find the optimal traveling route of an RFID reader which is used to search for missing objects in a cost-effective way. There are two alternatives in selecting RFID readers. One is to use a hand-held RFID reader only, while the other is to use both a fixed reader and a hand-held reader together. In both cases, numerous paths should be considered which can be derived from different heuristic policies and analyzed mathematically. The search for a missing object will begin with its most likely location based on probabilistic behavior pattern.

The rest of the paper is organized as follows. In Chapter II, we summarize previous studies on location estimation. In Chapter III, we give an overview of RFID technology. Mathematical models are explained in Chapter IV. Chapter V describes software implementation and analysis. Chapter VI concludes the paper and discusses future work.

CHAPTER II

LITERATURE REVIEW

Accurate locating or tracking is required in many fields from navigating for rescuing wounded people in emergency situation to decision-making for striking the target during the military operations. Therefore, the fields of the academic circles and the industries have been interested in locating and tracking objects or people over the years. The study is getting broad for inside as well as outside. Being able to rapidly locate equipment is critical in-building, including hospitals, manufacturing floors and warehouses. To utilize the limited budget and resources more efficiently, it is important to make optimal strategic decision. This chapter introduces established knowledge related to indoor location sensing using some devices such as infrared, wireless LAN, ultrasonic and RFID.

A. Infrared

Unlike a pager system, which needs a response from the recipient, or the access-control system, which inconveniently requires personnel to handle card-keys, an Active Badge is an innovative system that provides direct and automatical location information of people in an office environment [8]. An implementation of this system at ORL (Olivetti Research Ltd.) obtained good results in respect to the accuracy of locating people for meeting and for transferring telephone calls to the indicated person. However, since an Active Badge location system uses infrared signals, there are several limitations such that a badge has to be attached on the surface of clothes exposed in the air, the signals are hard to penetrate obstacles in an office or the range of the signals is not enough to detect distant tags.

[9] illustrates another approach based on infrared technology. This system tried to know the approximate position and orientation of the user's head by using infrared transmitters and Head-Mounted Displays. However, several drawbacks of this system, such as heavy weight of the head unit, restriction of head rotation range, and the large number of beacons in the ceiling, still exists. There are also the limitations as announced in the Active Badge system.

B. IEEE 802.11

[10] conducted research on the RF-based system for locating and tracking users in an in-building environment. In this study, RADAR were applied over a standard IEEE 802.11 based on [11] projected about a deployment of RF wireless LAN. NNSS (nearest neighbors in signal space) was the technique to get the distance between each the SS (signal strength) tuple. Through the empirical signal strength measurements and signal propagation modeling for signal strength information in advance, location-aware services and applications were available in the study. In spite of the hostile nature of the radio channels in side building, [10] provides that RADAR has an ability to locate and track users with a high degree of accuracy.

[12] presented several improvements on previous research [10]. First of all, their Viterbi-like algorithm was demonstrated to outperform both NNSS and NNSS-AVG in respect to accuracy. Facts of different environments such as the multipath phenomenon, the number of people in the building or different times of the day were affected to evaluate their system. Thus, [12] reinforced as using multiple Radio Maps

that represent the various environmental conditions. To analyze the effect of multiple floors, RADAR implemented the measurement on multiple floors as well.

Although some advantages, RADAR has nontrivial disadvantages. A wireless LAN, that may be impractical on small or power constrained devices, has to always assist the object to track. Moreover, the propagation model, which is preconfigured, must be reconstructed or created as a new model when the original environment is changed [13].

C. RFID

SpotON tagging system [14] for fine-grained location sensing utilized the RFID technology. Three dimensional location sensing based on radio signal strength analysis in a fundamental principle for determining the location of objects or people in SpotON project. On the contrary, there are some limitations that are clearly not desirable in a robust location sensing system : 1) only publishing the immediate location state of objects, 2) no data store or time sequence analysis, 3) a fixed API (application programming interface)

LANDMARC is a valuable instance that uses active RFID for in-building location sensing [7]. By using fixed location reference tags, their approach improves the accuracy and reliability, and reduces the error distance. In LANDMARC experiment, both the number of nearest neighbors and readers are analyzed how much effect to increase the location accuracy. The fact that two extremely different interferences are rarely influent to locate tags' placement raises the confidence for the proposed approach. As the accuracy depends on the density of the reference tags or the number of readers, however, the LANDMARC approach still suffers from the budget problem of RFID devices.

CHAPTER III

AN OVERVIEW OF RFID TECHNOLOGY

RFID is a technology that identifies an object or person automatically by using radio waves. RFID, which is a "no touch technology", can be used in surveillance, detection of counterfeiting, computation, tracking, and checking for objects in various fields of industry such as manufacturing, construction, and health care.

A. History of RFID

Since Michael Faraday identified the field of electromagnetism about the relationship between light and radio waves in 1845, people have pursued convenient and rapid technologies using electromagnetic properties. Radio Frequency Identification (RFID) technology is one of these. These technologies have been in existence since World War II. The precursory device of RFID technology was Leo Theremin's radio wave decoder that the Soviet government used for reconnaissance in 1940s. Related transponder technology was originated from a discrimination system used to distinguish friendly and enemy aircraft. Allied aircraft sent out a signal while passing near friendly forces, and the "Identification: Friend or Foe" (IFF) system identified the signal. Tracking technology is advancing and being used in everyday life more frequently. When customers order any product on the web or over the phone, they wonder where the package is and when it will be delivered. Customers can connect to the internet, enter the tracking number, and find that information. RFID is currently one of the most accurate tracking technologies.

B. Fundamental Components in an RFID System

An RFID system largely consists of tags (transponder), readers (transceiver) and middleware.

1. RFID Tag

A tag is a device that stores certain unique information. Tags are attached to products or people and then communicate with a reader when the reader receives radio waves. Here, both the chip and antenna are called a tag. This tag can also be classified into two groups [15] : a passive RFID tag which has no internal power source, and an active RFID tag which has its own power source. The benefits of passive RFID tags are that they are smaller, cheaper, unlimited in life span because power does not have to be supplied. The reading range, however, is shortened to around 10cm (ISO 14443) up to a few meters (ISO 18000-6) [16]. So, if tags are placed outside of the electromagnetic field, these devices do not work to detect. In comparison, active RFID tags [16][17] can have read ranges around one hundred meters and contain abundant memories with specific information. Also, active RFID tags can be used in a much wider number of industries because these tags can detect temperature, humidity and brightness. However, there are some disadvantages of using power for the tag's circuitry. The tag's life span depends on the battery; it stops working when the battery dies. Active RFID tags are also larger and more expensive than passive RFID tags.

2. RFID Reader

An RFID reader [15][17] connects with the tag and the host computer. The reader receives the tag's information and sends it through standard interface to the host computer. It creates a read zone between tags and readers. The tags emit identifiable radio waves and the readers receive this information through their internal antennas. The range of the read zone depends on both the reader's power and the frequency used to communicate as well as the tag used. Lower-frequency tags can be read from shorter distances and higher-frequency tags from longer distances. There are three basic kinds of RFID reader installations: hand-held, fixed reader installed in area, and fixed reader installed at chokepoint. These will be discussed later.

3. Middleware

Middleware [17] is software to integrate various data received from several readers. This means that middleware connects two disparate applications, reader and host computer, allowing these to pass information between them. Through middleware, users can get data from the reader for displaying on the host computer such as electronic product code (EPC) number, sales, date, inventory, and directions in the movement of hardware (tags and readers).

C. Different Technologies for Asset Tracking / Locating

When the tagged item moves in or passes by the electromagnetic fields, the chips in that tag are stimulated by radio waves. The chip is powered up and then broadcasts its data. Even though most tags operate similarly, their applications differ depending on the location of reader and the types of readers used [15][17].

1. Hand-held Reader

A handheld reader is a small, lightweight device that is used to find tagged items quickly and conveniently. Users can grip the hand-held reader easily and carry this while users look for specific things that they want in large and complicated areas. The user can determine how far away the desired tagged items are located through measure and display of the Received Strength Signal Indicator (RSSI).

2. Fixed Reader Installed in Area

A fixed reader is installed on a stationary point like a wall or a ceiling to read movement, location, or internal data of objects in the area. The reader collects the information continuously. Depending on the reader size (especially its antenna), the range and accuracy is greater than hand-held readers. In the other words, the antenna size of the tag and reader is important for range considerations because a bigger antenna can collect and broadcast more energy. For this reason, fixed readers are used mainly with active RFID tags.

3. Fixed Reader Installed at Chokepoint

A fixed reader at a chokepoint is the most common application of RFID. The operating principle of the reader is to read a signal whenever the tagged objects arrive or depart. Thus, consumers are able to see the flow of assets with ease. Moreover, it is efficient because all objects have to flow through the chokepoint. Fixed readers installed at chokepoints are used mainly with passive RFID tags.

D. RFID Frequencies

RFID is a technology based on correspondence of radio waves in electromagnetic fields. Understanding the relation between RFID and frequency can provide better knowledge about the application of RFID.

Low frequency (LF) is generally referred to as frequency in the range of about 30 - 300 KHz. RFID mainly uses 125 - 134 KHz frequencies. LF has short reading range, less than 2 meter (typically 1 Cm - 1.5 m) and transfers small data at rates of less than 1 kbit/s. However, it has the capability to penetrate water. High Frequency (HF) is 3 - 30 MHz, and the affected distance is less than 1 meter (typically 1 Cm - 0.7 m). HF can transfer data of approximately 25 kbit/s. Like LF, this frequency passes through water, but also metal. Ultra high frequency (UHF) is between 300 MHz and 3 GHz, mainly 868 MHz in Europe and 902 to 928 MHz in the USA. UHF reads up to 100 m and transfers 1kbit/s, but it can not penetrate both water and metal. As typical microwave frequency is 2.45 GHz, it can read long distance and transmit data at high rates. Because of these differing characteristics, the application is also different for each frequency range[18][19]. LF is used for access control systems, HF for liquid products or access cards, UHF for supply chain applications, and microwave frequency for toll booths on a highway. Table I shows different frequencies that are used for different applications [20].

Table I. Different Applications by Different Frequencies in RFID

LF	HF	UHF	Microwave
Access control	Supply chain	Supply chain	
Livestock Tracking	Ticketing	Logistics	Emerging technologies
Race timing	Wireless commerce	Warehousing	Asset tracking
Auto immobilizers	Product authentication	Pallet tracking	
Wireless commerce		Asset tracking	

E. RFID Standards

With the expansion of RFID in industry, standardization for RFID becomes more important. The purpose of RFID is convenient and rapid application, but if it is not easy to interact with different locations or items, it will not serve its purpose. Thus, two types of standards are considered here: Data standards and Technology standards [2].

Data standards can provide unified data through the electronic product code (EPC, Figure 1). The EPC is a unique code number which has same structure in every tag. This code, which was invented by MIT Auto-ID Center, is divided into four partitions. The two-digit header number identifies the length, structure, type, version and generation of EPS. EPS manager number means the company contained in the production of the manufacturer. With 28 bits, the EPS manager is able to cover as many as 228 companies. Object class represents the stock keeping unit (SKU) when applied to retail products. This is related to retail application. A serial number is used to identify each product; it can share about 68 billion items. Hence, the EPC will not be repeated for different items[17][18].

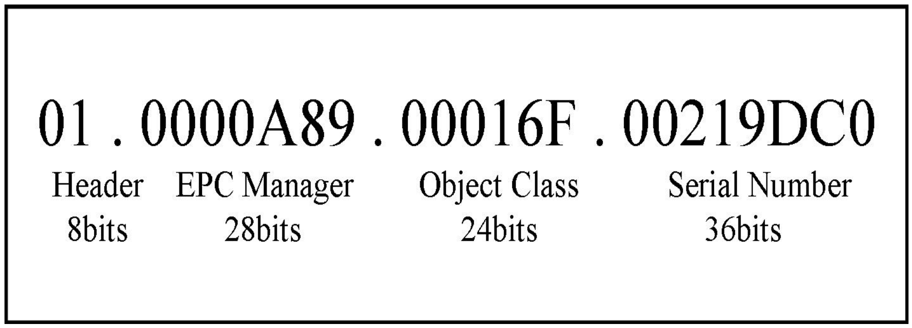

Fig. 1. Electronic Product Code (EPC)

Technology standards, that are different to EPC data structure, are associated with air interface (frequency) between RFID tags and readers. There are several standards [15] such as the following: ISO 15693 (Smart Labels), ISO 14443 (Contactless payments) and ISO 11784 (Livestock), but the ISO 18000 standards family is used most widely.

- ISO 18000-2 (LF) : under 135 KHz
- ISO 18000-3 (HF) : 13.56 MHz
- ISO 18000-4 (Microwave) : 2.45 GHz
- ISO 18000-7 : 433 MHz

Even though these various standards exist, there are some problems such that one RFID tag does not enable interoperability with the reader of different manufacturers. However, ISO 18000-6 A/B (UHF) tried to communicate with RFID hardware by different manufacturers, and second generations by EPC global and ISO 18000-6 C (passive UHF) have agreed to interoperate their data. The unification of technology standards will improve the utility of RFID.

F. RFID vs Barcode

RFID is expanding its use to industry, education and the others more widely. However, RFID tags will not replace every barcode, but RFID obviously has distinct advantages over the barcode.

- RFID tags are more difficult to counterfeit because each chip has a unique serial number, while barcode can be duplicated easily because they are printed on paper.
- Barcodes should scan products one by one, but RFID tags can scan items from far away automatically without human intervention.
- RFID does not rely on line-of-sight.
- RFID tags can store more data than barcodes do.
- RFID tags can read and write as well as revising.
- RFID tags are not affected by harsh environments, while barcodes are.

G. Example of RFID Implementations

An example of RFID tracking is HealthTrax announced by InfoLogix [21], which is used for real time location tracking (RTLT) of medical devices. HealthTrax RFID tag is 802.11 Wi-Fi-based and leverages the existing wireless infrastructure attached to hospital devices (such as infusion pumps, portable x-ray machines and patient monitoring devices), as well as other mobile assets (such as wheelchairs, computers on wheels, stretchers and gurneys) and then tracks the equipment in real-time. As a result, hospital personnel can know the locations of needed devices. The doctors, nurses and maintenance staff can concentrate on their own work, not wasting their effort and time looking for the equipment they need. Hospitals can save millions of dollars annually on the value of equipment, and provide convenient and rapid medical assistance to patients. Hospitals can also monitor their patients' location if the patients leave a designated area, as HealthTrax also has a patient tracking system.

It is essential to recognize inventory levels especially in huge warehouses such as Walmart, Costco etc. Companies can predict their next orders easily and accurately, by recognizing current inventory so they can react to rapid market changes. Moreover, it prevents loss of backorders and decreases of their holding costs on overstock. Accordingly, it is critical to know the inventory level. Data system management is applied to it. Sometimes there may be a mismatch in the inventory level where an item is stocked and the number of on hand inventory provided by the data management system. Customer may "relocate objects" in places other than the objects assigned location. Rearrangement of relocated items is very time-consuming and a waste of workforce. With the application of RFID technology, companies will be able to check inventory in less time and with less labor-force.

CHAPTER IV

OPTIMAL AND PROPOSED TRAVELING ROUTE MODEL

Location-recognition applied to asset management by RFID is different from location-recognition using GPS, Infrared, and Radar. The purpose of applying RFID is minimizing searching time, effort, and investment cost by guiding the detector when there is a missing item. This chapter is composed of four sections. Section A provides the model setup for RFID technology. Section B provides traveling route determination for general object tracking. In addition, four heuristic policies for determining the efficient traveling route are suggested in section C. Finally, section D proposes an expected time model for hand-held and fixed RFID readers.

A. Model Setup

There are three types of RFID readers as mentioned. One type of fixed reader, at chokepoint, measures information about location change. It is advantageous to set up the reader in front of the door. This reader is allowed to record whether the item has passed through the reader before. The item's heading direction is unknown when installing only one reader. However, the recorded time difference between two readers installed at a certain distance will be able to find the heading direction. A second type of fixed reader, located in a room, tells whether an item is in a certain area or not. Setting up this reader in a large area may improve performance and cost efficiency. The third type of reader is hand-held, and leads the searcher to the terminal location of a tagged item.

Hand-held RFID has two main operating modes. Continuous mode scans the tagged item strength level continuously in repeating cycles within a specified range. We considered using data from the hand-held in continuous mode to find the location. Although we would be able to know the signal strength level, we would not be guaranteed its correct distance because dynamic interferences are affecting the range. In addition, the distance is changed by other items in the same area, so it is hard to standardize the criteria. Second, exception mode reports to the reader when a tagged item is detected in the configured range. We use exception mode scanning in our model.

We assume that a hand-held identifies the objects in the minimum distance in order to suggest following search paths. Furthermore, we assume that a searcher can predict the location where s/he can find the item location. When the searcher does not have any background about the room, even though the searcher holds the RFID hand-held in the certain area, it is difficult to suggest a certain heuristic policy. In this case, the searcher just does an exhaustive search. On the other hand, if we have enough information about a certain room, the possible location of a tagged item or the path of search can be predicted. In the next section, we consider how to track the location of a tagged item.

B. Traveling Route Determination for General Object Tracking

We assume that the object we are supposed to find is located in a given room. The size of the room is X (width) and Y (length). We initially assume that the tag is located in any given location inside the room with equal probability. In other words, if the searcher moves randomly, the probability that the item is detected is uniform for searching location and time. The following rectangles (Figure 2) represent one room and a curved path line in the rectangle represents a searching path. For exhaustive searching, Route 3 is more efficient than the others because scanning without overlapping in a room is the most suitable searching method.

Let the area of the room be $X \times Y$ and let the detecting radius of the sensor be r. Let v_1 be the searching velocity from the left edge to the right edge when the seacher walks parallel with the bottom line of the room. Then, when $t = \frac{X}{v_1}$, an area of $2rv_1t$ has been searched completely by the hand-held sensor. The minimum searching time for exhaustively touring an room is defined as $T_e = \frac{XY}{2rv_1}$. This is the same as the measured time when the path of a searcher follows the Route 3 in Figure 2. Therefore, we assume that the traveling route of a searcher follows this Route.

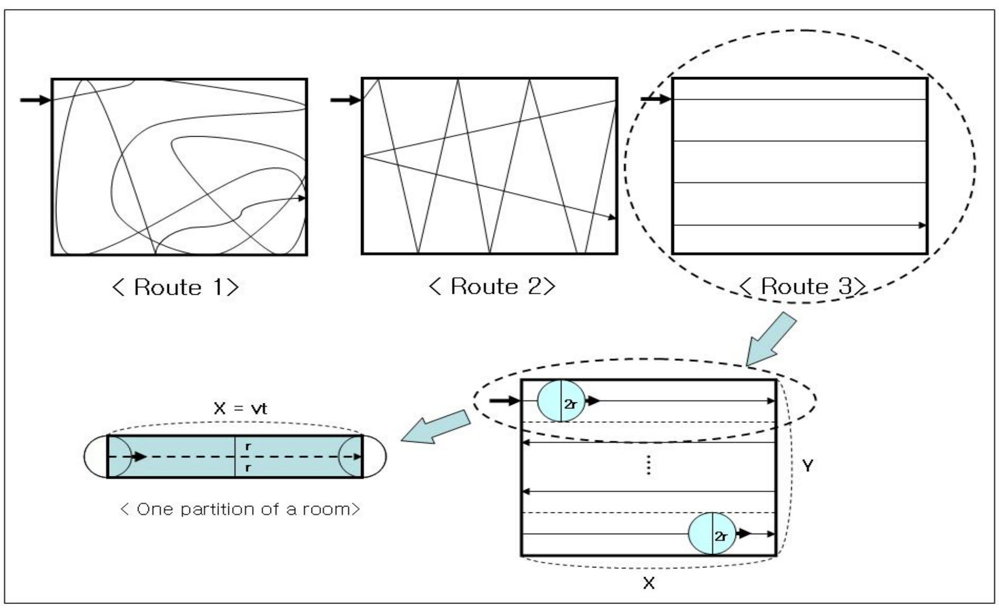

Fig. 2. Possible Search Routes of a Room

Let T denote a random variable that represents the time required to find the tagged item when assuming the item is in this room. As stated in the previous paragraph, we know that it takes T_e seconds to search the entire room, and under the assumption that the tagged item is in the room, the probability that the tagged item is found within t_p seconds is uniformly distributed as the following pdf,

$$t_p = \frac{1}{T_e} \qquad 0 \leq t_p \leq T_e$$

By the definition of $\mathbf{E}[\mathbf{T}]$ (expected value of T), the expected time to find an object is as follows : $\mathbf{E}[\mathbf{T}] = \frac{1}{2} \times T_e$. Here, there is one more factor to consider. Using a handheld reader to detect the tag within a radius r, we need to manually look for the tag by opening cabinets, drawers, etc. The manual time to find the tag is dependent on radius r. Define the time to find the tagged item manually by $h(r)$. The expected time, $g(r)$, to find the tag in the room, given that tag is in the room is

$$g(r) = \frac{1}{2} \cdot T_e + h(r)$$

As r increases, the time to find the approximate location is decreased, but the time to do the fine-search increases.

Now consider a room that is divided into N subsections. The objective is to find the optimal travel path of the searcher. We assume that the indices of N subsections of the room are given as in Figure 3. We assume that for each subsection i the probability that the tagged item is in subsection i is known and given by $\bar{p}_i$. Let p_i be the reordered $\bar{p}_i$ such that the subsection with the highest probability is given the lowest index, $p_1 > p_2 > \cdots > p_N$. The lower index subsection means a faster visiting order

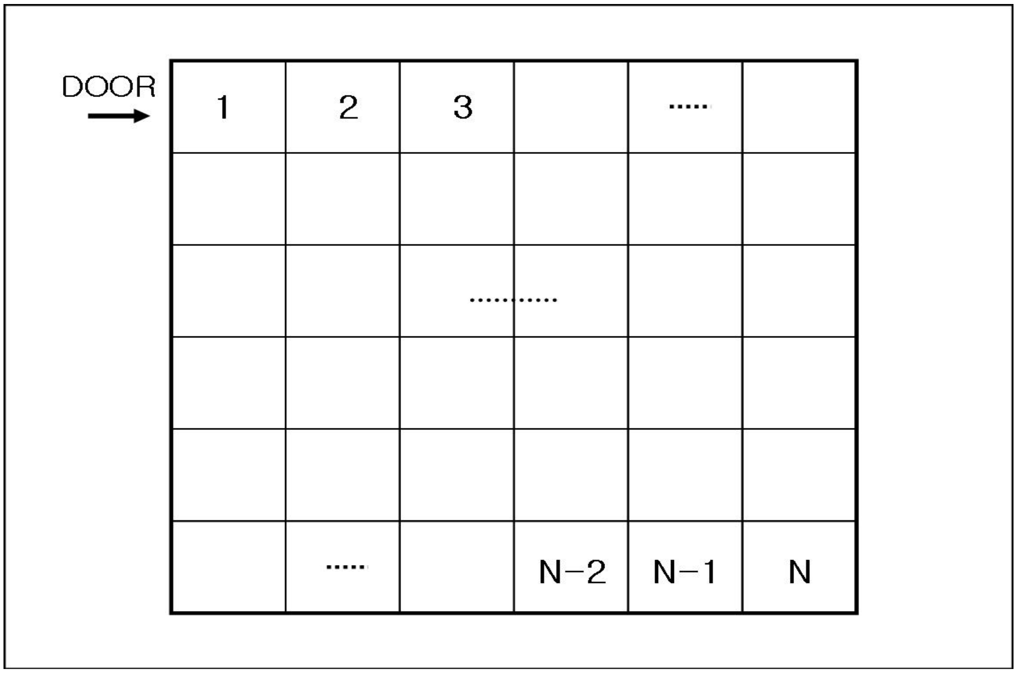

Fig. 3. The Index of N Subsections of the Given Room

(Figure 4). Let t_e be the time to do the exhaustive search of one subsection. Let x be the width of each subsection and y be the length of each subsection.

Furthermore, for $O_i = j$, let i be the order that a searcher visits subsection j. That is, if a seacher goes first to the subsection k, then $O_1 = k$. Also, if subsection l $(k \neq l)$ is second, then $O_2 = l$. Let $d_{j-1,j}$ be the shortest distance moving from subsection $j-1$ to subsection j. Indeed, if the missing item is in the i^{th} subsection, it can be arranged as the following expression :

$$\mathbf{E}[\mathbf{T} \mid \text{Tag} = i] = \underbrace{\sum_{j=1}^{i} \frac{d_{O_{j-1},O_j}}{v_1}}_{\text{moving time}} + \underbrace{\frac{t_e}{2}}_{\text{time to find now}} + \underbrace{(i-1) \times t_e}_{\text{previous search time}}$$

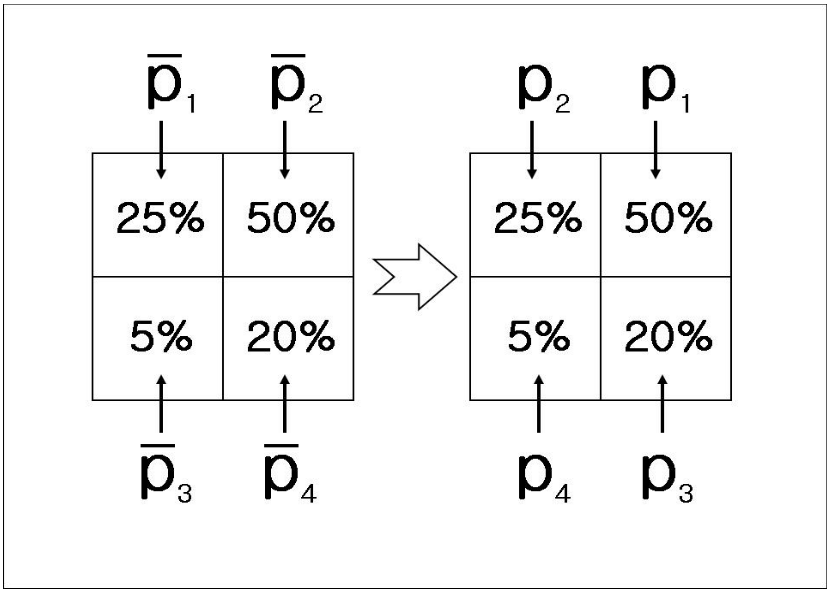

Fig. 4. Meaning of $\bar{p}_i$ vs. p_i

$$+ \underbrace{h(r)}_{\text{manual time}},$$

where Tag is the random variable to represent the location of the missing item.

The expected time, $\mathbf{E}[\mathbf{T}]$, taken to search the tag within the room with hand-held reader is expressed as the like:

$$\mathbf{E}[\mathbf{T}] = \sum_{i=1}^{N} p_i \times E(T|Tag = i)$$

Therefore, we can formulate the time required for a general traveling route to detect the tagged item with the following model :

Objective function :

$$\min_{O_1,O_2,\cdots,O_N} \sum_{i=1}^{N} p_i \times \Big(\sum_{j=1}^{i} \frac{d_{O_{j-1},O_j}}{v_1} + (i-1) \times t_e + \frac{t_e}{2} \Big) + h(r)$$

Constraints :

$$O_i \neq O_j, \quad for\ i \neq j$$

$$1 \ \leq \ O_i \ \leq \ N \quad for\ i = 1, \ldots, N$$

$$O_i \quad integer \quad \text{and} \quad O_0 \quad initial\ location(DOOR)$$

The optimal solution to this optimization problem gives as the vector $(O_1, O_2, \cdots, O_N)$, which tells us the optimal sequence of visiting the subsections. Touring N divided subsections of the room requires evaluating $N!$ paths which is typical NP (non polynomial time) hard problem. Thus, we propose heuristic policies in order to come up with search sequences without having to solve this optimization problem.

C. Traveling Route Determination by Four Heuristic Policies

The first heuristic policy is an exhaustive searching from beginning to end. It is the basic approach but this heuristic policy can be applied when the given information is unclear, or when it is hard to determine realistic values for the set of belief of the searcher.

The second heuristic policy is when the most probable area is searched first. This heuristic policy is considered in two ways: detecting and non-detecting. Considering probability turning off the reader while traveling is non-detecting. On the contrary, probability turning on the reader while traveling is detecting.

In the last heuristic policy, both distance and probability are considered to decide a traveling route. In other words, every single time a searcher travels each room, the searcher decides the next subsection based on the distance from current location and the probability of the tag's location.

1. First Heuristic Policy: Brute-force Method

This heuristic policy ignores information about the probable location of the item. Entering the room, a searcher tours all subsections in order from the left subsection to the right, and from the upper location to the lower, as in Figure 3. The subsection that the searcher visits initially is given the lowest index. To avoid detecting the tag in the other subsection during searching the current subsection, we need to restate t_e mentioned before. Assume that the overlapping search allows the only last partition (Figure 5). Thus, with hand-held, the time to do an exhaustive search of a subsection i, when the searching path follows Route 3, is given below.

Let R_c be the repeated number of searches from edge to edge in each subsection from top to bottom. That is

$$R_c = \frac{y}{2r}$$

The value of R_c is then rounded up to the nearest integer. And t_e is restated like this

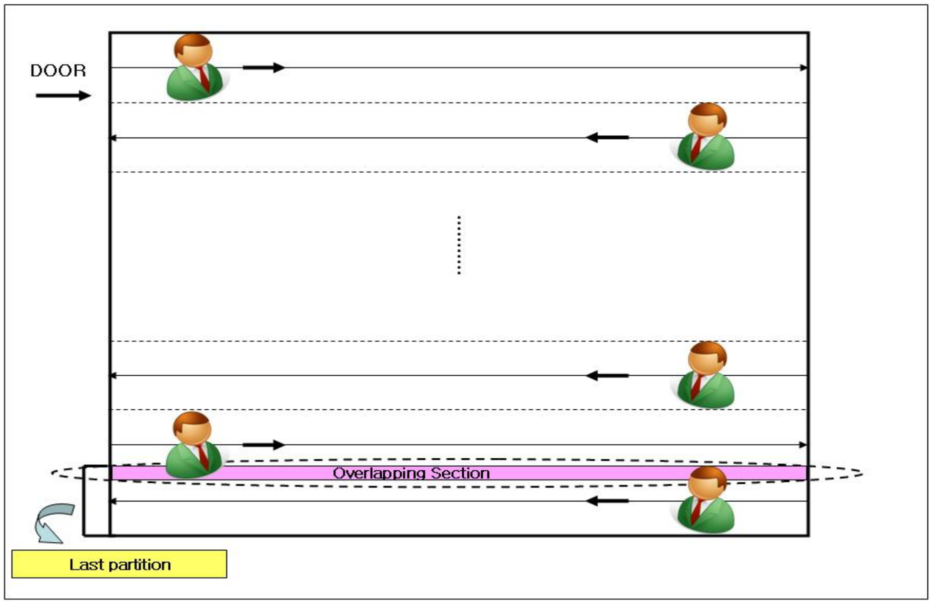

Fig. 5. Revised Traveling Route in a Subsection

$$t_e = \frac{x}{v_1} \times R_c$$

As announced in the second section of this chapter, since each subsection is uniformly distributed that has the same probability for containing the item, let p_i(i=1, 2, $\cdots$, N) denote the probability that the tagged item is located in subsection i. We can generalize the total expected time to do an exhaustive search of the entire room with hand-held reader.

(1) Amount of time to search for the tag in a subsection 1

$$\bar{p}_1 \times \left(\frac{x}{v_1} \times R_c \times \frac{1}{2}\right) = p_1 \times t_e \times \frac{1}{2}$$

(2) Amount of time to search for the tag in a subsection 2

$$\bar{p}_2 \times \Big(t_e + t_e \times \frac{1}{2}\Big)$$

$$\vdots$$

(i) Amount of time to search for the tag in a subsection i

$$\bar{p}_i \times \Big((i-1) \times t_e + t_e \times \frac{1}{2}\Big)$$

Therefore, the expected time to find the item when doing an exhaustive search of the entire room is

$$\mathbf{E^1}[\mathbf{T}] = \sum_{i=1}^{N} \bar{p}_i \times \Big((i-1) \times t_e + t_e \times \frac{1}{2}\Big)$$

2. Searching by Priority: Second and Third Heuristic Policies

This heuristic policy is based on prioritizing areas to search first. The location with frequent visits has higher priority. In example from section G in Chapter III, surgical equipment can be found in an operation room, and medical supplies can be found in a medical locker. The most frequently visited area in Walmart should be searched first. This can be a short cut to find the missing item quickly. Searching with item location history can lead the way with less time and less efforts.

• Second Heuristic Policy: The case of non-detecting during movement between subsections

The subsections are given subscript indices according to the probability that the tagged item is detected. Let $d_{(i,j)}$ be the distance between the leaving subsection which has the i^{th} highest probability and the entering subsection that the j^{th} highest. Assume that a searcher moves faster than a searching velocity in a subsection because the searcher does not have to look over in detail between the subsections. That is, v_2 is a moving velocity between the subsections, and $v_2 > v_1$. According to this heuristic policy, the expected time to find the item when doing an exhaustive search of the entire room is as follows.

$$\mathbf{E^2}[\mathbf{T}] = \sum_{i=1}^{N} p_i \times \Big(\sum_{j=0}^{i} \frac{d_{(j,i)}}{v_2} + (i-1) \times t_e + t_e \times \frac{1}{2} \Big)$$

- Third Heuristic Policy: The case of detecting during movement between subsections

Consider that a searcher moves between the subsections with hand-held. Different to the second heuristic policy, detecting a missing tagged item may occur accidently. The previous heuristic policy overlooks the potential detecting during movement between subsections. Although the probability of passing subsections from leaving subsection to entering subsection is relatively small, the third heuristic policy considers that a searcher can get the tagged item much earlier if the area of between subsections has a little of the probability for searcher to find the missing tag. In this case, we assume that the moving velocity between the subsections is slower than the velocity applied in the second heuristic policy. Assume that the moving velocity is same as v_1. Therefore, in this case, the expected time to do an exhaustive search of the entire room is represented as follows. Let X be a detection in i^{th} subsection

$(i = 1, \cdots, N)$ and Y be a detection movement between the subsections $(j = 0, 1)$. By Bayes' Rule,

$$\begin{aligned}\mathbf{E^3[T]} &= \sum_{j=0}^{1}\sum_{i=1}^{N} E(T|X=i, Y=j)\cdot P(X=i, Y=j) \\ &= \sum_{i=1}^{N} E(T|X=i, Y=0)\cdot P(X=i, Y=0) \\ &\quad + \sum_{i=1}^{N} E(T|X=i, Y=1)\cdot P(X=i, Y=1)\end{aligned}$$

Let Z be the status that a searcher is heading to the entering subsection $s(s = 1, \cdots, N)$.

$$\begin{aligned}\mathbf{E^3[T]} &= \sum_{i=1}^{N} E(T|X=i, Y=0)\cdot P(X=i, Y=0) \\ &\quad + \sum_{s=1}^{N}\sum_{i=1 s\neq i}^{N} E(T|X=i, Y=1, Z=s)\cdot P(X=i, Y=1, Z=s)\end{aligned}$$

Therefore, since we know the expected time when finding the tagged item in a subsection only,

$$\begin{aligned}\mathbf{E^3[T]} &= \sum_{i=1}^{N} p_i \times \Big((i-1)\times t_e + t_e \times \frac{1}{2}\Big) + \sum_{s=1}^{N}\sum_{i=1 s\neq i}^{N} E_{is}[T]\cdot P_{is} \\ &= \sum_{i=1}^{N} p_i \times \Big((i-1)\times t_e + t_e \times \frac{1}{2} + \sum_{s=1 s\neq i}^{N} E_{is}[T]\cdot P_{is}\Big)\end{aligned}$$

where $E_{ij}[T]$ is the expected time and $P_{(ij)}$ is the probability that a searcher finds the tag during movement between subsection i and j.

3. Fourth Heuristic Policy: The Case of Considering Both the Probability and the Distance

The fourth heuristic policy is considering the probability and the distance to go to the next searching subsection. For this strategy, we need a criterion to express the trade-off between going to the high probability subsection and the distance to get there. We are necessary to verify to find the optimal expectation time of the results obtained by the fourth heuristic policy when we give how much weight to the distance. Let us suppose that a searcher is at subsection i. J_i is the index set of subsections that a searcher has not toured until now. Index $j^\star$ of subsection that will search to next step is decided as follows.

$$j^\star = argmin_{j \in J_i}\left(\frac{q_j}{\sqrt{\sum(q_j - \overline{q})^2/(N-1)}} + \lambda \cdot \frac{d_j}{\sqrt{\sum(d_j - \overline{d})^2/(N-1)}}\right), \quad (4.1)$$

where $q = \frac{1}{p}$ and λ is a weight to distance term. $\overline{q}$ is a geometric mean, $\overline{q} = (q_1 \cdot \cdots \cdot q_N)^{\frac{1}{N}}$ and $\overline{d}$ is a arithmetic mean, $\overline{d} = \frac{1}{N}\sum d_i$. Note that each term is standardized to balance the different scales between the probability and the distance. Based on this idea, we represent the expected time as follows.

$$\mathbf{E^4}[\mathbf{T}|\lambda] = \sum_{i=1}^{N} p_{j_i^\star} \times \Big(\sum_{k=1}^{i} \frac{d_{j_{k-1}^\star, j_k^\star}}{v_2} + (i-1) \times t_e + t_e \times \frac{1}{2} \quad \Big)$$

In the special case of the fourth heuristic policy, when $\lambda = \infty$, this heuristic policy is same as the first heuristic policy, and when $\lambda = 0$, this heuristic policy is same as the second heuristic policy, also when $\lambda = 1$, a condition of the distance and the probability is considered equally for deciding the next traveling route. We will discuss how to get optimal $\lambda^\star$ that can minimize the expected searching time in section B of Chapter V.

D. Traveling Route Determination that Added Fixed Reader in the Room

In previous section, the four heuristic policies assume that a searcher utilizes only a hand-held reader. However, in some circumstances, a fixed reader can be used in addition to the hand-held. In this experiment for detecting the tag in the given room, a fixed reader is installed in a room. After sensing by fixed reader the part of a room, a searcher with hand-held reader reduces the searching area of the given room without difficulties. In this section, the solution method for the proposed model is introduced.

1. Expected Time Model for Hand-held and Fixed Reader

Suppose that we installed some fixed readers and all of the subsections in the room, where we are searching a missing item, are grouped into M sub-groups ($M \leq N$), so that the sensing results of the fixed readers can determine whether the missing item is located at one of the sub-groups, depending on the range and the installed location of the fixed readers. Let the set S_m be the set containing the indices of the subsections which belong to the sub-group m for $1 \leq m \leq M$. Then, the possibility of finding missing item in the sub-group m is defined as the followings:

$$P_m = \sum_{i \in S_m} p_i,$$

where p_i is the possibility that the item is located in the i^{th} subsection.

Define $E(T_m|Tag1 = m)$ as the expected time taken to search the tag when the tag is in the sub-group m. $Tag1$ is a random variable to represent the sub-group which has the missing item. Then, the expected time, $\mathbf{E}[\mathbf{T}]$, taken to search the tag within the room in which the fixed readers are installed is expressed as the like:

$$\mathbf{E}[\mathbf{T}] = \sum_{m=1}^{M} P_m \times E(T_m|Tag1 = m) \tag{4.2}$$

Comparing to being only a hand-held to search, installing a fixed reader is required an additional cost. Thus, in order to get in less time and with less workforce to find the missing item, the best method of several models proposed in this chapter should be chosen.

CHAPTER V

EXPERIMENTAL RESULTS AND PERFORMANCE EVALUATION

In this chapter, we present a computational study of the practical application of the model proposed in Chapter IV. To obtain the data for the optimal result, we consider a scenario according to a building layout. Through those results, the most efficient heuristic policy is analyzed and decided in the given circumstance.

This chapter is organized as follows. Section A details experiments used to obtain numerical results using the optimal function proposed in Chapter IV. Through the numerical results, the section analyzes better installation locations for fixed RFID readers. Section B uses simulation for dealing with more general problems. From the simulation results, we verify more important conditions to find the tagged objects.

A. Experiment and Analysis (2 × 2 square area)

1. Only Hand-held Reader

The numerical data used in the model are based on the scenario below.

The different colors of Figure 6 present the different probabilities in each subsection of a room. The darker colors express higher probability that the tag exists in that subsection. We assume that a searcher carries a handheld reader while looking for specific items such as hospital devices, missing items, or other assets. The detecting radius of the sensor of RFID handheld is 1 meter, and the searching velocities of detecting and non-detecting during movement in the room are, respectively, 1 m/s

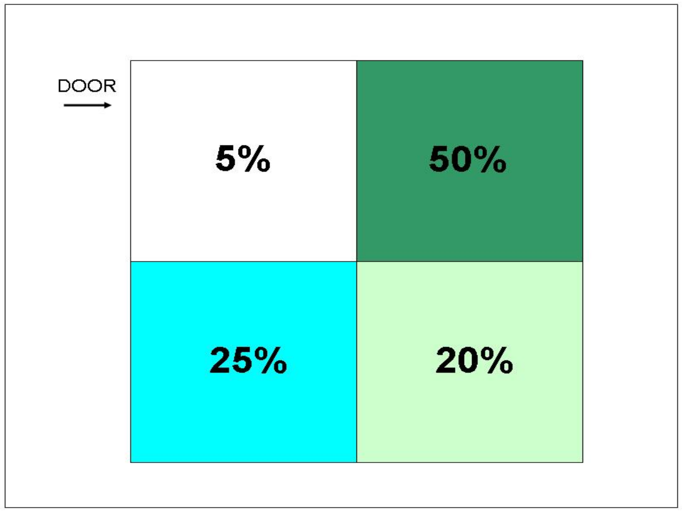

Fig. 6. A Room Made by a Given Scenario

and 0.5 m/s. Also, assume that the room size is 16 meters by 16 meters, and each subsection is a square which is 8 meters both in length and width.

We suppose that the probabilities that the tagged item exists in a given subsection i ($\bar{p}_i$) are as in Table II. Actually, the measurement of the probability can be calculated from values obtained by the study of human motion estimation ([22], [23]). But, in this paper, we suppose that the probabilities are known as in Table II.

Table II. Probabilities of Given Room

Subsection 1	Subsection 2	Subsection 3	Subsection 4
5 %	50 %	25 %	20 %

When we solve above scenario manually, the optimal path of 24 possible paths is $2 \Rightarrow 3 \Rightarrow 4 \Rightarrow 1$. And the result of the optimal expected time, $\overline{T}$, to find the tag is

$$
\begin{aligned}
\overline{T} &= \min_{O_1,\cdots,O_4} \sum_{i=1}^{4} p_i \times \Big(\sum_{j=1}^{i} \frac{d_{O_{j-1},O_j}}{v_1} + (i-1) \times t_e + \frac{t_e}{2} \Big) \\
&= p_1 \times (\sum_{j=1}^{1} \frac{d_{O_{j-1},O_j}}{v_1} + \frac{t_e}{2}) + p_2 \times (\sum_{j=1}^{2} \frac{d_{O_{j-1},O_j}}{v_1} + t_e + \frac{t_e}{2}) \\
&\quad + p_3 \times (\sum_{j=1}^{3} \frac{d_{O_{j-1},O_j}}{v_1} + 2 \times t_e + \frac{t_e}{2}) + p_4 \times (\sum_{j=1}^{4} \frac{d_{O_{j-1},O_j}}{v_1} + 3 \times t_e + \frac{t_e}{2}) \\
&= 92.3
\end{aligned}
$$

We had a solution about the number of $N!$ permutations should be solved when the room was divided by N possible subsections. In other words, the room which is divided into 2 by 2 square area has to be checked with the different 4! permutations. Detecting the tag that is in given room with only hand-held, the provided result is solved without unnecessary repeated calculation when the heuristic policies, that is based on higher priority, is applied to calculate. However, it is not guaranteed that the application of those heuristics always induces the optimal solution.

The next step provides the results for better location that the fixed reader is installed in the room, either the most probable area or the farthest area, as well as for the large sets of scenario instances. Section 2 refers for shortened duration in accordance with existence of the fixed reader in the room.

2. With Hand-held and Fixed Reader

The formula to get the duration that detects the tagged item by using both hand-held and fixed reader is already shown in (4.2). From (4.2), we express the formula to find the optimal value with hand-held and fixed reader as follows.

$$\mathbf{E}[\mathbf{T}] = \sum_{m=1}^{M} P_m \times \left(\min_{O_1, O_2, \cdots, O_N} \sum_{i=1}^{N} \frac{p_i}{P_m} \times \Big(\sum_{j=1}^{i} \frac{d_{O_{j-1},O_j}}{v_1} + (i-1) \times t_e + \frac{t_e}{2} \Big) \right) \quad (5.1)$$

s. t.

$$O_i \neq O_j, \quad for\ i \neq j$$
$$1 \leq O_i \leq N \quad for\ i = 1, \ldots, N$$
$$O_i \quad integer \quad \text{and} \quad O_0 \quad initial\ location(DOOR)$$

The detection time to find the missing item is affected by the location of a fixed reader in a room. We can consider two different plausible types of installed locations : the most possible location (Figure 7) and the farthest location, the opposite location from the door (Figure 8). In here, we test which one is the more efficient installation location of the fixed reader.

As one fixed reader is installed, the room has 2 sub-groups ($M = 2$) as known in the objective function(5.1).

a. Case of Installing the Fixed Reader in the Most Probable Area

The case that the fixed reader is located in the most probable subsection: 1) if the fixed reader detects the tag, then a searcher checks that subsection(subsection 2) only with hand-held, 2) if not, then a searcher travels remaining subsections(subsection 1, 3 and 4) to find the tag. The duration is expressed as a following expansion.

$$\mathbf{E}[\mathbf{T}] = \sum_{m=1}^{2} P_m \times \left(\min_{O_1, \cdots, O_4} \sum_{i=1}^{4} \frac{p_i}{P_m} \times \Big(\sum_{j=1}^{i} \frac{d_{O_{j-1},O_j}}{v_1} + (i-1) \times t_e + \frac{t_e}{2} \Big) \right)$$

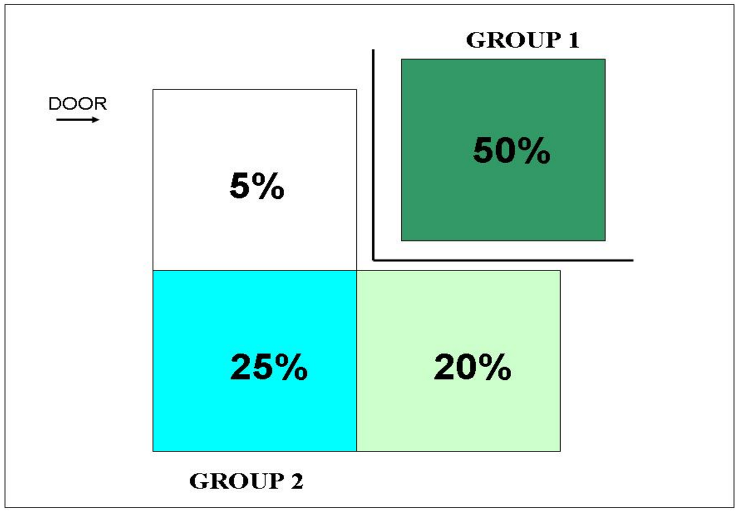

Fig. 7. Most Possible Location of the Fixed Reader

$$
\begin{aligned}
&= P_1 \times \Big(\frac{p_1}{P_1} \times (\sum_{j=1}^{1} \frac{d_{O_{j-1},O_j}}{v_1} + \frac{t_e}{2})\Big) \\
&+ P_2 \times \left(\min_{O_1,\cdots,O_3} \sum_{i=1}^{3} \frac{p_i}{P_2} \times \Big(\sum_{j=1}^{i} \frac{d_{O_{j-1},O_j}}{v_1} + (i-1) \times t_e + \frac{t_e}{2}\Big)\right) \\
&= 61.3 \qquad (5.2)
\end{aligned}
$$

b. Case of Installing the Fixed Reader in the Farthest Area

The case that the fixed reader is located in the farthest location from the door is much the same as the previous case. That is, when the fixed reader detects the missing tag, a searcher looks for only the installed area, but not, a searcher searches for others. The result is expressed as follows.

$$
\begin{aligned}
\mathbf{E}[\mathbf{T}] &= \sum_{m=1}^{2} P_m \times \left(\min_{O_1,\cdots,O_4} \sum_{i=1}^{4} \frac{p_i}{P_m} \times \Big(\sum_{j=1}^{i} \frac{d_{O_{j-1},O_j}}{v_1} + (i-1) \times t_e + \frac{t_e}{2}\Big)\right) \\
&= P_1 \times \Big(\frac{p_1}{P_1} \times (\sum_{j=1}^{1} \frac{d_{O_{j-1},O_j}}{v_1} + \frac{t_e}{2})\Big)
\end{aligned}
$$

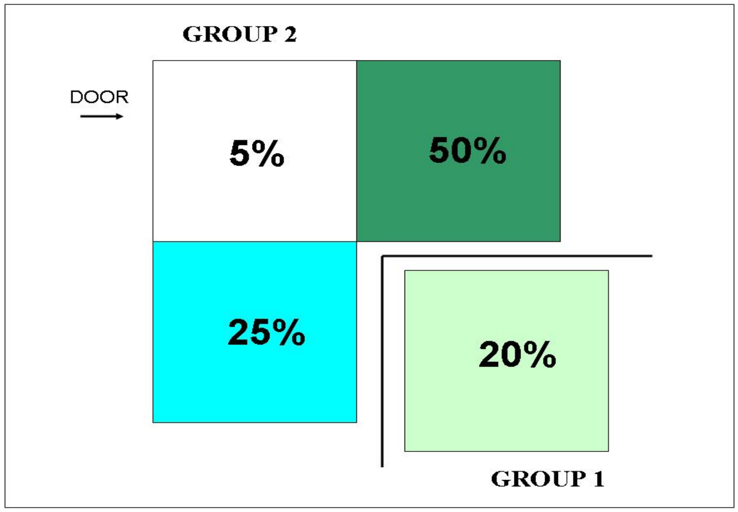

Fig. 8. Farthest Location of the Fixed Reader

$$+ \quad P_2 \times \left(\min_{O_1,\cdots,O_3} \sum_{i=1}^{3} \frac{p_i}{P_2} \times \Big(\sum_{j=1}^{i} \frac{d_{O_{j-1},O_j}}{v_1} + (i-1) \times t_e + \frac{t_e}{2} \Big) \right)$$
$$= \quad 64.06 \tag{5.3}$$

Comparing to (5.2) and (5.3) in these examples, the fixed reader installed at the most probable location is more efficient. Each best traveling route in the uninstalled subsections of both cases is to follow in the order of high probability as well.

Table III. Estimated Result for Different Room Size

Room size	Hand-held (sec)	Hand-held and Fixed reader Most(sec)	Hand-held and Fixed reader Farthest(sec)	Time saving (%)
$16m \times 16m$	92.30	61.30	64.06	33.6
$24m \times 24m$	200.30	130.30	136.59	34.9
$32m \times 32m$	349.90	224.90	236.33	35.7
$40m \times 40m$	541.10	345.10	363.26	36.2

From the optimal results calculated in section 1 and 2, the time difference in accordance with existence of the fixed reader in the room is very wide. Installation of the fixed reader gets the time saving of 33.6% rather than the optimal search time of only hand-held in this case. We run same more experiments with different room size. Table III is the estimated result. In these experiments, when the size of length and width is twice, the time of 35.7% is saved. That is, the larger the room size is, the more benefit we obtain from fixed reader.

When the number of the fixed readers is limited, the efficiency of the readers depends on both the installation location and probability distribution.

3. Extension of Experiments

This section presents more general analysis of the practical application of the heuristic policies and installation location of the fixed reader. We have conducted diverse sets of experiments to examine the influence of probabilities and install location.

In scenario 1, we change the applied probabilities based on the scenario cited at the beginning of this section. For verifying what affects to the searching time, we apply various compounded sets of the probabilities in the scenarios. In this scenario, the second and third higher probabilities are made different sets, and at the same time the two remaining probabilities are fixed like the Table IV. Scenario 1 is divided into two large examples. That is, the first example is $\bar{p}_3 > \bar{p}_4$: from sample 1 to sample 8. The second example is $\bar{p}_4 > \bar{p}_3$: sample 9 to sample 16.

Appling Table IV, Figure 9 plots the result for search time to detect the tagged

Table IV. Changed Probabilities of Scenario 1

	Subsection					Subsection			
	1	2	3	4		1	2	3	4
sample 1	5 %	50 %	30 %	15 %	sample 9	5 %	50 %	22 %	23 %
sample 2	5 %	50 %	29 %	16 %	sample 10	5 %	50 %	21 %	24 %
sample 3	5 %	50 %	28 %	17 %	sample 11	5 %	50 %	20 %	25 %
sample 4	5 %	50 %	27 %	18 %	sample 12	5 %	50 %	19 %	26 %
sample 5	5 %	50 %	26 %	19 %	sample 13	5 %	50 %	18 %	27 %
sample 6	5 %	50 %	25 %	20 %	sample 14	5 %	50 %	17 %	28 %
sample 7	5 %	50 %	24 %	21 %	sample 15	5 %	50 %	16 %	29 %
sample 8	5 %	50 %	23 %	22 %	sample 16	5 %	50 %	15 %	30 %

item. The graph shows that when the differences between the second and third probabilities are small, the differences in search times also decrease. Although obtaining good results for the searching time from sample 9 to 13 when the fixed reader is installed in the farthest, the difference of the result is too small to recognize as Table IX (APPENDIX A). Thus, installing the fixed reader in the most probable area is better than installing in the farthest area. Optimal results of each sample is illustrated as a searcher travels in the order of descending probabilities (optimal travel route of scenario 1 in APPENDIX A).

Table V is the scenario in the case that the probabilities of the room, divided into 2 $\times$ 2 square area, are going on almost equal. The least probability increases gradually, and then the most one decreases. Like scenario 1, the remaining two probabilities are fixed as well.

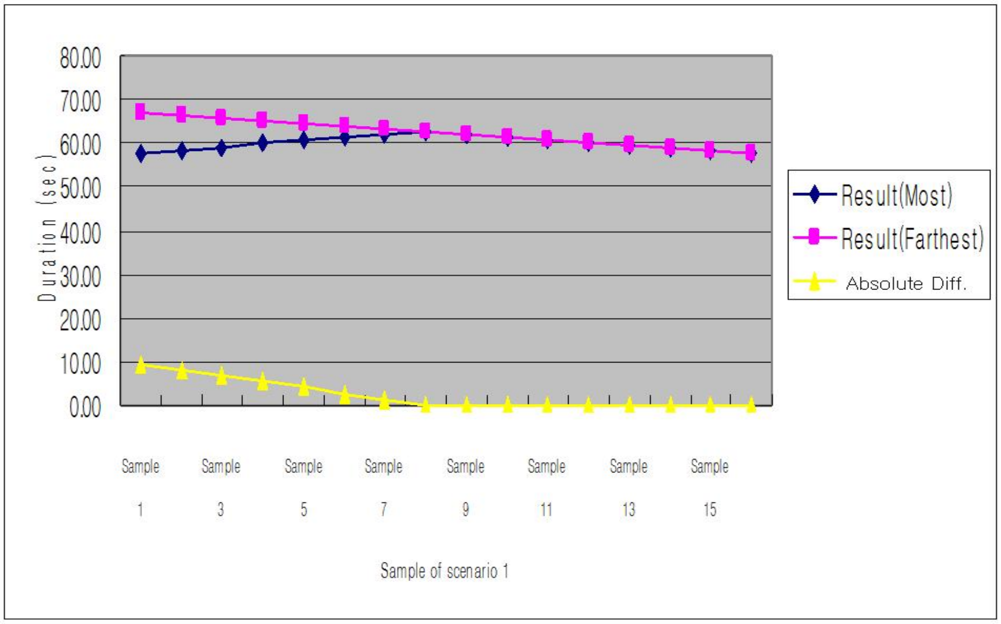

Fig. 9. Search Time to Find the Tag for Scenario 1

Figure 10 shows that installing the fixed reader at the most probable area is adequate in every caes. Up to sample 9, the difference between the two results is uniform, but after sample 9, the gap grows bigger. As announced in the scenario 1, the reason is that the differences of each probability is small. From sample 10, the order of the traveling route is not in accordance with previous scenarios. In this sample, there is no fixed reader in the travel path of the sub-group and Instead the fixed reader is installed in subsection 2. Then, the traveling path follows the area subsections $1 \Rightarrow 3 \Rightarrow 4$. This unique result implies that the traveling route is influenced by the distance as well as the probability as we expect in Chapter IV. Thus, in the next section, we experiment and analyze which is the better heuristic policy among four heuristics proposed in Chapter IV. Furthermore, we verify which one is more effective to decide the traveling route of the searcher between the probability and the distance.

Table V. Changed Probabilities of Scenario 2

	Subsection					Subsection			
	1	2	3	4		1	2	3	4
sample 1	1 %	54 %	25 %	20 %	sample 8	15 %	40 %	25 %	20 %
sample 2	3 %	52 %	25 %	20 %	sample 9	17 %	38 %	25 %	20 %
sample 3	5 %	50 %	25 %	20 %	sample 10	19 %	36 %	25 %	20 %
sample 4	7 %	48 %	25 %	20 %	sample 11	21 %	34 %	25 %	20 %
sample 5	9 %	46 %	25 %	20 %	sample 12	23 %	32 %	25 %	20 %
sample 6	11 %	44 %	25 %	20 %	sample 13	25 %	30 %	25 %	20 %
sample 7	13 %	42 %	25 %	20 %	sample 14	27 %	28 %	25 %	20 %

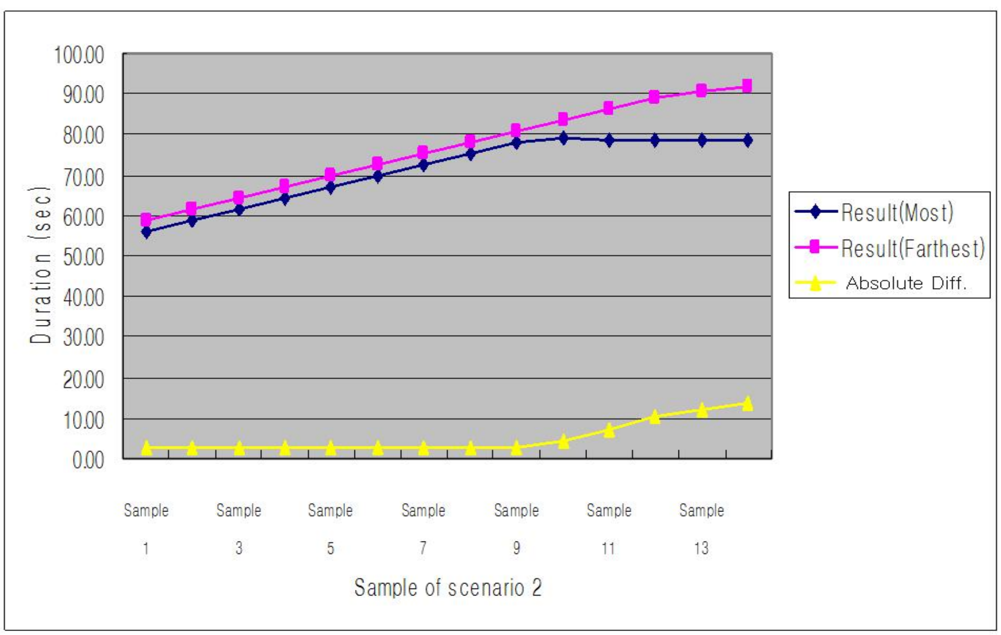

Fig. 10. Search Time to Find the Tag for Scenario 2

Scenario 3 and 4 (APPENDIX B) provide the sets of probabilities that subsection 2 and 3 change, and the sets of probabilities that subsection 2 and 4 change, respectively. The results of scenario 3 and 4 are similar to previous scenarios. That is, installing the fixed reader at the most probable area gets a little more benefit than at the farthest area. The resource tables, graphical results and numerical results for scenario 3 and 4 are in Appendix B.

The location of the most probablity moves to the closest subsection from the enterance of the room. Scenario 5 to 8 also follow all resources that were indicated in the head of this section except sets of probabilities. We have a curiosity whether or not we also have a time benefit when the fixed reader is installed at the most probable area.

As checking various instances of scenario 1 to 4, in scenario 5 to 8, we use many sets to analyze how much effect the change of probability in each subsection is. In Table VI shows that the ratio of the second and third highest probabilities changes. Scenario 5 uses the resources of Table VI.

Figure 11 depicts the graphical result for scenario 5. From sample 7, the case that the installation location of the fixed reader is at the farthest area is more efficient. The reason is an increase of the possibility that detects the tag in subsection 4. Traveling route (optimal travel route of scenario 7 in APPENDIX A) follows the order of probabilities in remaining subsections except being the fixed reader.

Table VII show that the least probability increases gradually, and then the most

Table VI. Changed Probabilities of Scenario 5

	Subsection					Subsection			
	1	2	3	4		1	2	3	4
sample 1	50 %	5 %	30 %	15 %	sample 7	50 %	5 %	24 %	21 %
sample 2	50 %	5 %	29 %	16 %	sample 8	50 %	5 %	23 %	22 %
sample 3	50 %	5 %	28 %	17 %	sample 9	50 %	5 %	22 %	23 %
sample 4	50 %	5 %	27 %	18 %	sample 10	50 %	5 %	21 %	24 %
sample 5	50 %	5 %	26 %	19 %	sample 11	50 %	5 %	20 %	25 %
sample 6	50 %	5 %	25 %	20 %	sample 12	50 %	5 %	19 %	26 %

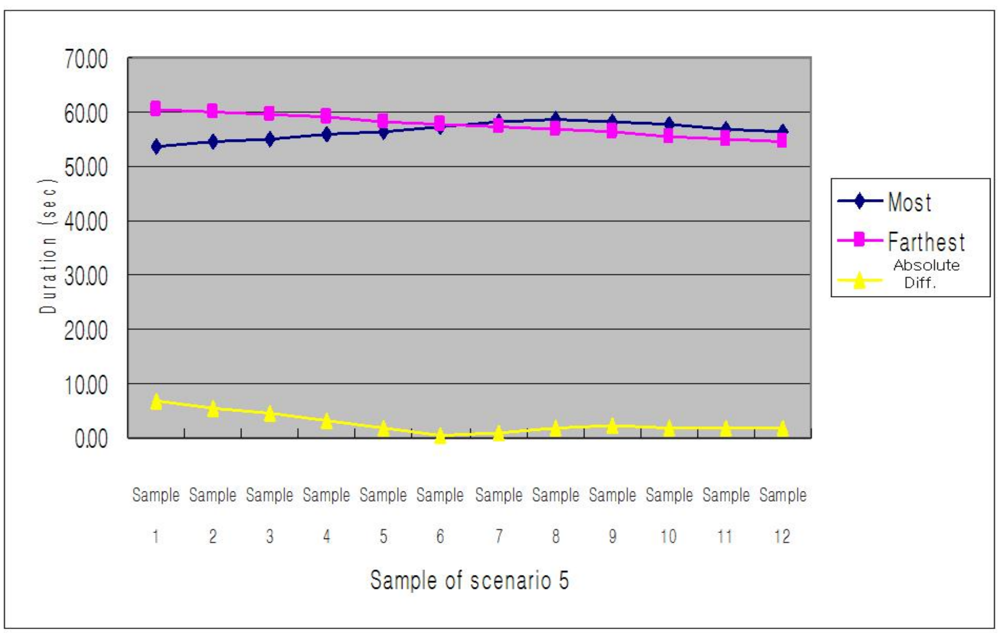

Fig. 11. Search Time to Find the Tag for Scenario 5

one decreases. In the scenario 6, the deviation of probabilities of each sample is going on small.

Table VII. Changed Probabilities of Scenario 6

	Subsection					Subsection			
	1	2	3	4		1	2	3	4
sample 1	54 %	1 %	25 %	20 %	sample 8	40 %	15 %	25 %	20 %
sample 2	52 %	3 %	25 %	20 %	sample 9	38 %	17%	25 %	20 %
sample 3	50 %	5 %	25 %	20 %	sample 10	36 %	19%	25 %	20 %
sample 4	48 %	7 %	25 %	20 %	sample 11	34 %	21%	25 %	20 %
sample 5	46 %	9 %	25 %	20 %	sample 12	32 %	23%	25 %	20 %
sample 6	44 %	11%	25 %	20 %	sample 13	30 %	25%	25 %	20 %
sample 7	42 %	13 %	25 %	20 %	sample 14	28 %	27 %	25 %	20 %

Seeing the numerical results of Table XIV (APPENDIX A), as the value of the most probability gradually decreases, a searcher can save the search time a little more when the fixed reader is in the farthest area. As the result of scenario 3, the distance element influences the traveling route. By this influence, the outputs of the sample 13 and 14 are shown that the most probable area is better than the farthest. However, as Figure 12 depicts, the results of Table XIV are much the same (less than 1 sec, APPENDIX A), it does not matter wherever the reader is installed.

Scenario 7 and 8 (APPENDIX C) show the importance of the occupying weight of the probability in each subsection. In these scenarios, when either the probability of the farthest area is higher than 20% or the probability(20%) grows bigger relatively,

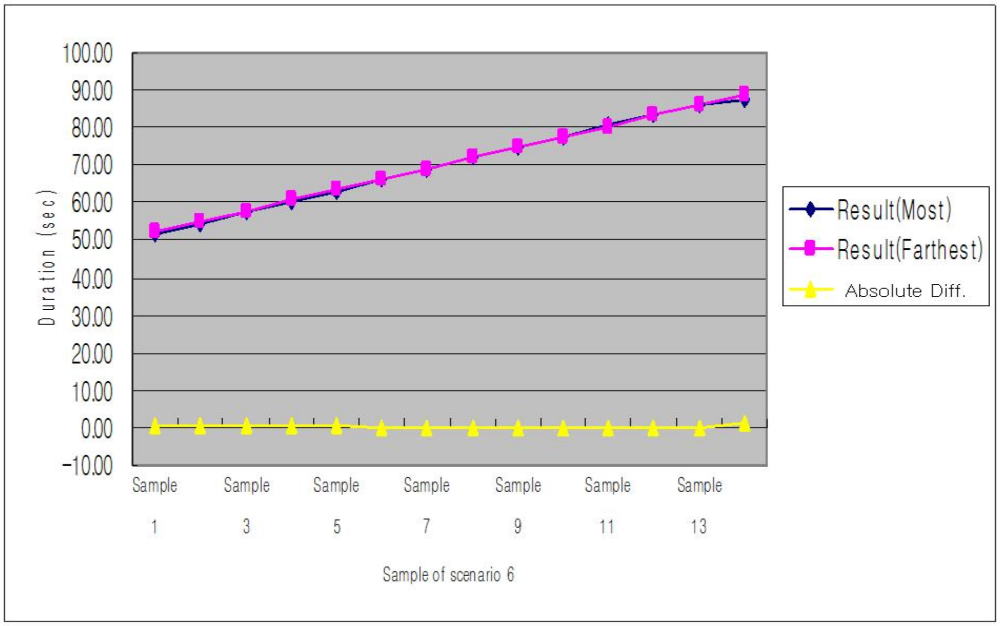

Fig. 12. Search Time to Find the Tag for Scenario 6

the installation at the farthest area is better than that at the most area. The resource tables, graphical results and numerical results for scenario 7 and 8 are contained in Appendix C.

B. Experiment and Analysis Using Simulation

This section develops the room layout for approaching to a little more actual interior. As mentioned in advance, for detecting the tag in the room which divided into N square areas, $N!$ possible traveling routes are examined. For instances, if the given room is divided into 3×3 square area, the number of different combinations will increase up to $9!$ $(= 362880)$ to get to optimal traveling route. To attain this optimal traveling route is computationally very expensive. Therefore, in this section we provide results using a the simulation, implemented in MATLAB. To verify our simulation model, we need to calculate the optimal function manually, and then compare the result to the data provided from the simulation.

In this section, we introduce how to operate the simulation. The reliability of the simulation will be established. We analyze which of the heuristics performs best. We verify which one is more effective to decide the traveling route of the searcher between the probability and the distance. That is, which of the probability and the distance gives a decisive influence to the optimized λ value of (4.1).

1. Simulation Set Up

We test the effectiveness of the simulation under variable conditions such as the length and width of the room, the detecting velocity and non-detecting velocity, the sensing radius of the hand-held, and the number of subsections in the room. Also, we assume that probability of the missing item is located in each subsection and we simulate the tag's location by this probability. We use this to get the statistically reasonable result. Once simulation starts, the simulated sensor moves in the room according to each proposed heuristic policies. When the tag is within the radius of hand-held reader, the searching job stops and the duration is measured. For the next iteration, the tag's location is simulated again and the same procedures are applied until the last iteration. We average the duration of all trials of each heuristic policy to determine a long-run average time to find the tag for each of the heuristics.

Table VIII. Reliability Comparison for Simulation

	Optimal Value of Scenario 1 (sec.)			Simulation value (sec.)		
	Only hand-held	Most	Farthest	Only hand-held	Most	Farthest
sample 1	105.40	64.90	70.83	112.34	63.95	73.98
sample 2	102.10	64.90	67.53	100.47	62.32	65.69
sample 3	92.30	61.30	64.06	93.41	61.93	63.59
sample 4	82.50	57.70	60.60	82.98	57.93	57.52
sample 5	72.70	54.10	57.13	72.95	53.65	55.38
sample 6	58.98	46.42	49.53	57.01	45.86	47.55

2. Verifying for Reliability of Simulation

To verify the reliability of the MATLAB code we made, this section compares the results of the simulation with the expected from the given formulas in simple cases. Table VIII indicates outcomes for each estimation. The difference of the results by optimal function and simulation is an average of only 0.36%. Thus, we can see this simulation is reliable.

3. Experiment and Analysis by Using MATLAB (3×3 square area)

The experiments aim at analyzing the results of the suggested four heuristic policies by changing the range of the probability between the subsections when a searcher travels the room to find the missing item quickly.

Scenario 9 provides the results for the four resources of scenario instances in Appendix D. In Figure 13, the experiments are conducted by adjusting their range from

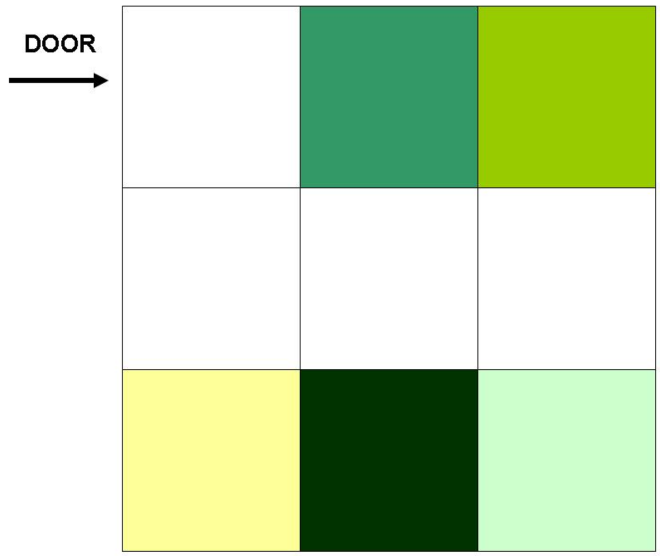

Fig. 13. Room Layout of Scenario 11

the highest probability to the lowest one. Figure 13 is a common layout of an office, market or warehouse. This room is typically arranged with a few pieces of furniture, equipment, electrical office appliances or shelves on opposite wall sides. There is also a path in the middle of the room. To apply various room sizes for the same layout of the room, we put in resources of several subsections by 2 meters from the initial 2 meter size up to 20 meters. To generate the result data, we repeated each test 1000 times.

Figure 14 to Figure 17 is the graphical result of minimum time to detect the missing item. These results are applied from resource 1 to resource 4 respectively as hand-held reader only uses. Following heuristic policies 2 and 3, the order of the traveling route is $8 \Rightarrow 2 \Rightarrow 3 \Rightarrow 9 \Rightarrow 7 \Rightarrow 1 \Rightarrow 4 \Rightarrow 5 \Rightarrow 6$. Compared to the above heuristic policies 2 and 3, the order of the traveling route of the heuristic policy 4 is followed as $2 \Rightarrow 3 \Rightarrow 8 \Rightarrow 9 \Rightarrow 7 \Rightarrow 1 \Rightarrow 4 \Rightarrow 5 \Rightarrow 6$. As the inside of a room is divided into many subsections, the traveling route among the heuristic

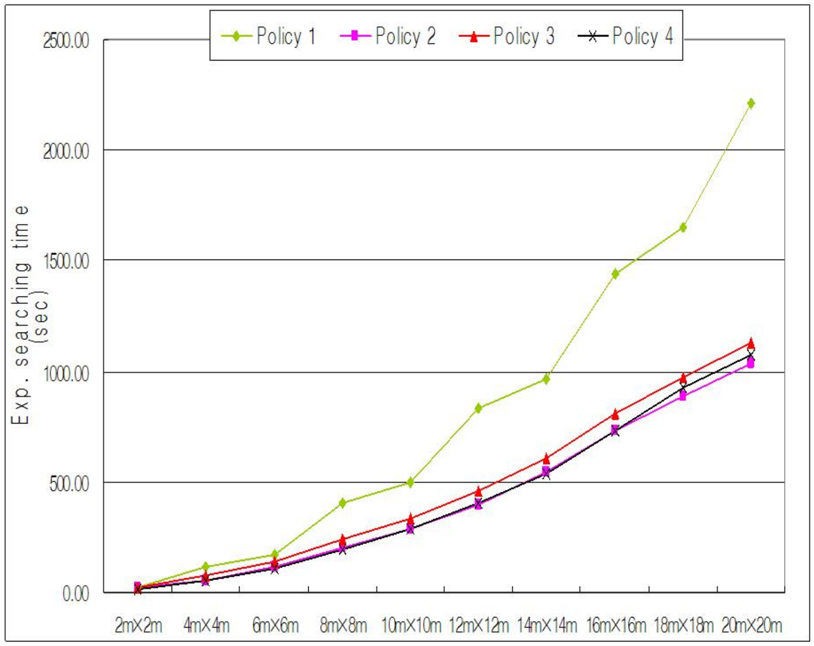

Fig. 14. Graphical Results of Resource 1 on Scenario 9

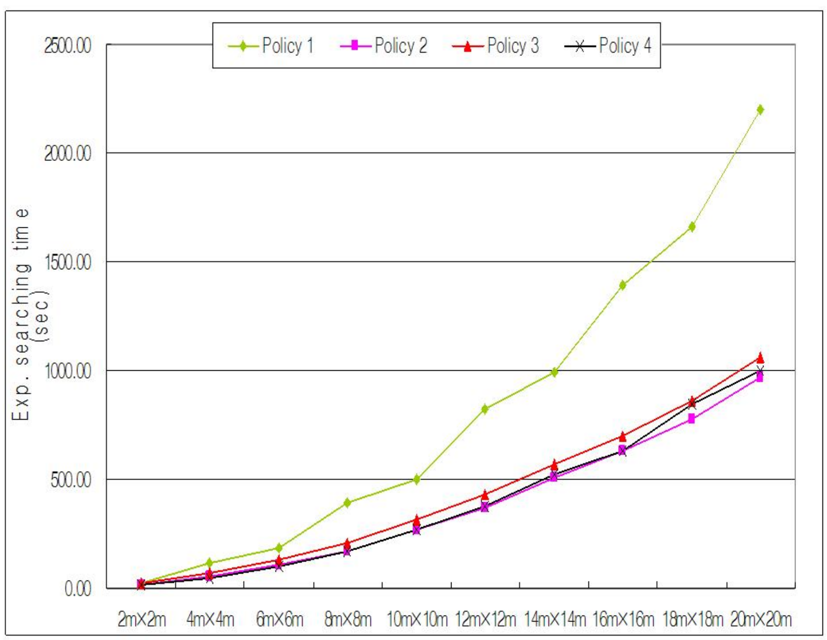

Fig. 15. Graphical Results of Resource 2 on Scenario 9

policies becomes definitely different. It implies that the moving distance influences deciding the next searching subsection. However, as the subsection's size increases, the minimum time to find the tagged item in the suggested situations changes from heuristic policy 4 to heuristic policy 2. That is, as the size of the subsection is gradually increasing, the detection time becomes smaller. From the results, when the room size is small enough, compared to the time to find the tag for every heuristic policy is not as significant. In this case, since the difference of detecting time is very small, we can ignore the difference. Figure 14 to Figure 17 depict that the result applied to resource 4 approaches heuristic policy 2 faster than the result applied to resource 1. In other words, the second heuristic policy is more adequate when having apparent information for the location of the tag in a room.

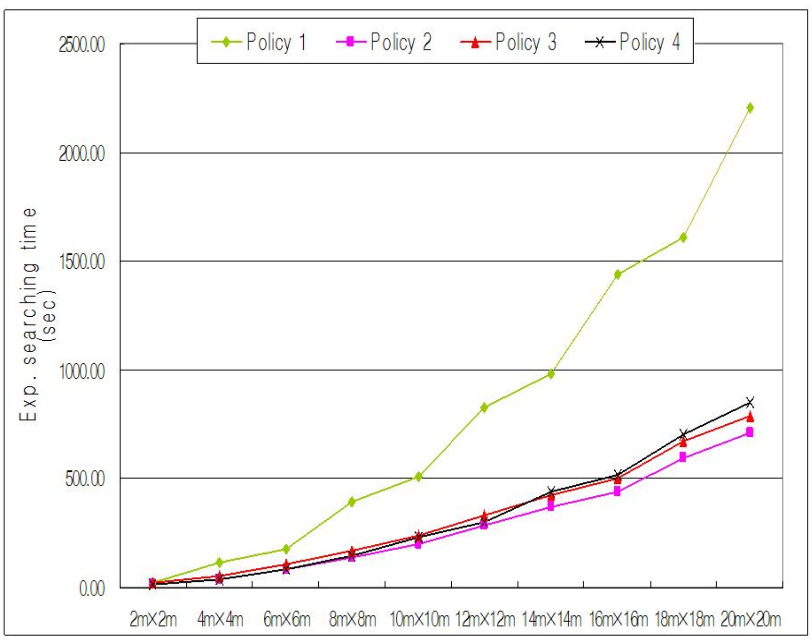

Fig. 16. Graphical Results of Resource 3 on Scenario 9

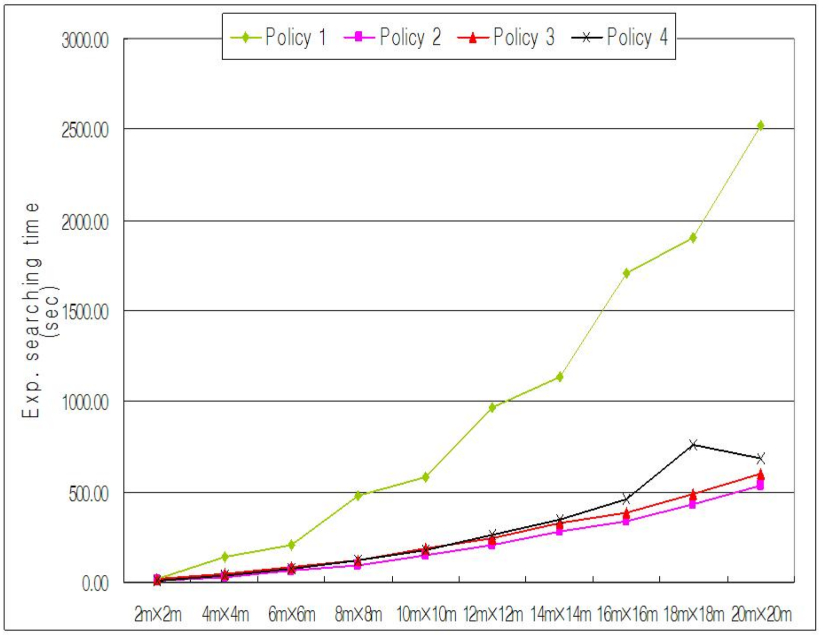

Fig. 17. Graphical Results of Resource 4 on Scenario 9

4. λ Study: Relation between the Distance and the Probability

To get the optimized λ value, $\lambda^\star$, $\mathbf{E^4}[\mathbf{T}|\lambda]$ is calculated in every step where λ starts from 0.1 up to 2 in increments of 0.1. $\lambda^\star$ is the optimal λ that minimizes $\mathbf{E^4}[\mathbf{T}|\lambda]$. That is,

$$\lambda^\star = argmin_\lambda \mathbf{E^4}[\mathbf{T}|\lambda]$$

Figure 18 provides the graphical results of $\lambda^\star$ when applying resources (APPENDIX D) of scenario 9 to the heuristic policy 4. The graphs shows that the optimal value of λ gets smaller as each subsection size increases. That is, in scenario 9, the expected detection time depends more on the probability of the subsection with the increased subsection size.

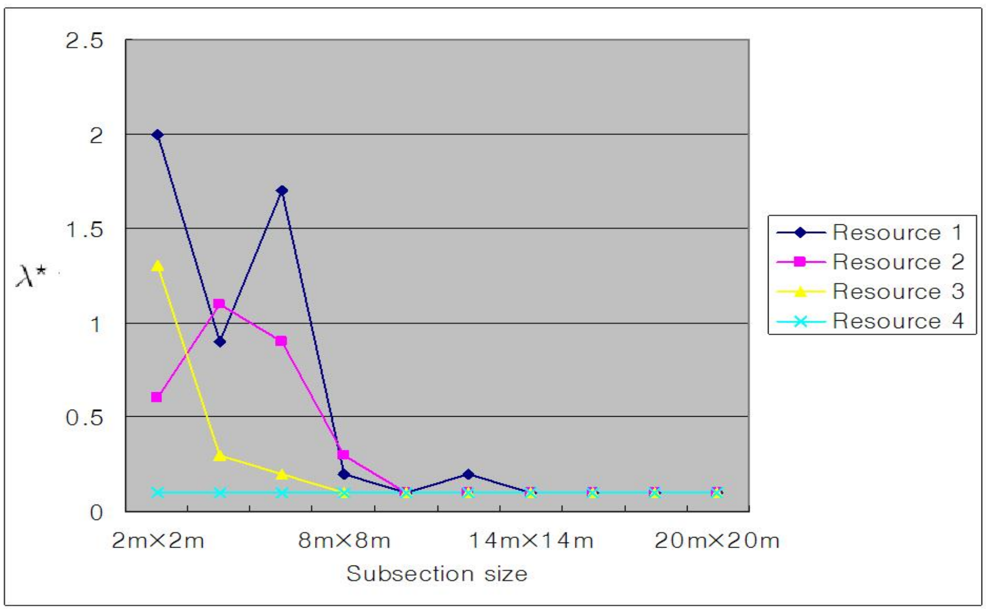

Fig. 18. Optimal λ Value for Each Configuration

CHAPTER VI

CONCLUSIONS AND FUTURE WORK

A. Conclusions

We demonstrated how to find the location of an item by using RFID in real time indoors to track equipment. Our performance criterion is expected time to find the object. Chapter IV presents a mathematical model of using RFID for efficient asset location. When there is a missing item, the purpose of applying RFID is minimizing searching time, effort, and investment cost by guiding the detector (hand-held reader only, or hand-held and fixed RFID reader). Touring N divided subsections of the room requires evaluating $N!$ paths which is typical NP hard problem. Thus, four heuristic policies are proposed in order to come up with search sequences without having to solve the suggested optimization problem. Moreover, as fixed readers in addition to the hand-held are used, this chapter suggests the model that a searcher reduces the searching area of the given room without difficulties.

In Chapter V, the analysis of the computational results on the optimal model proposed in Chapter IV is provided first with a simple scenario. There are several important findings and result from the experiments and these can be summarized as follows. Also, from the extension of experiments for verifying what affects to the searching time by the fluctuations in probabilities of each subsection, we obtain several useful findings. That is, using stationary readers in addition to hand-held readers will yield higher benefit than using only hand-held. Also, the optimal location of the stationary reader depends on the prior probability distribution of the location of the object. In particular, there are cases where it is not optimal to install the stationary reader in the location of the highest object location. The simple priority-based heuristic performs well in the practical problems.

B. Future Works

Until now, we jut have considered about rectangle shape room and subsection. However, in the futures works, we will experiment diverse layout and the room being obstacles. And, with using the stationary reader at chokepoint as well as two different readers, we will try to find optimal traveling route and install location of the fixed reader in extending indoor space like one floor of building or a whole building.

Moreover, in the hand-held reader, an operator can use the reader for short range applications as well as for long range applications by the given environment. Based on this, when a searcher uses the reader for long range first and then the hand-held reader detects a tag, the searcher can adjust the range short. It helps to reduce the searching time to find the missing objects. Let t_{e1} be the expected time to do an exhaustive search of one subsection as the range of hand-held is r_1. That is, $t_{e1} = \frac{x}{v_1} \times \frac{y}{2r_1}$. And let t_{e2} be the expected time to do an exhaustive search of a part made by long range as the range of hand-held is r_2, $(r_1 > r_2)$. That is, $t_{e2} = \frac{r_1}{v_1} \times \frac{r_1}{2r_2}$. Also, $\bar{d}_{j-1,j}$ be the shortest distance moving from subsection $j-1$ to subsection j when the range of the hand-held is r_1. Therefore, we can formulate the optimal mathematical programming as the following model :

$$\min_{O_1,O_2,\cdots,O_N} \sum_{i=1}^{N} p_i \times \Big(\sum_{j=1}^{i} \frac{\bar{d}_{O_{j-1},O_j}}{v_2} + (i-1) \times t_{e1} + \frac{t_{e1}}{2} + \frac{t_{e2}}{2} \Big) + h(r_2)$$

This idea will help to reduce the searching time and our efforts.

REFERENCES

[1] H. Stockman, "Communication by Means of Reflected Power," in *Proc. of the I.R.E*, 1948, pp. 1196–1204.

[2] H. Jung, F. Frank Chen, and B. Jeong, *Trends in Supply Chain Design and Management: Technologies and Methodologies*, chapter 2, London: Springer-Verlag, 2007.

[3] "Radio frequency Identification Feasibility Studies and Pilot Programs for Drugs," Dec. 2006, http://www.fda.gov/oc/initiatives/counterfeit/rfid_cpg.html.

[4] "Europe Protects Against Animal Disease Epidemics with Philips RFID," Dec. 2006, http://www.embeddedstar.com/press/content/2004/3/embedded13251.html.

[5] J. Young, "Healthcare and Pharmaceutical Industries," White Paper Revolutionizing Asset Management and the Supply Chain, Feb. 2005.

[6] "Global positioning system," Dec. 2006, Wikipedia, http://en.wikipedia.org/wiki/GPS.

[7] L. M. Ni, Y. Liu, Y. C. Lau, and A. P. Patil, "LANDMARC: indoor location sensing using active RFID," in *Proc. IEEE International Conference on Pervasive Computing and Communications (PerCom 2003)*, Mar. 2003, pp. 407–415.

[8] R. Want, A. Hopper, V. Falcao, and J. Gibbons, "The Active Badge Location System," *ACM Transactions on Information Systems*, vol. 40, no. 1, pp. 91–102, Jan. 1992.

[9] R. Azuma, “Tracking requirements for augmented reality,” *Communications of the ACM*, vol. 36, pp. 50–51, 1993.

[10] P. Bahl and V. N. Padmanabhan, “RADAR: An In-Building RF-based User Location and Tracking System,” in *Proc. IEEE Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2000)*, Mar. 2000, pp. 775–784.

[11] V. Hayes, S. J. Kerry, and A. Petrick, *Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification*, New York: IEEE Standards, 1999.

[12] P. Bahl, V. N. Padmanabhan, and A. Balachandran, “Enhancements to the RADAR User Location and Tracking System,” Tech. Rep., Microsoft Corporation, Redmond, WA, Feb. 2000.

[13] J. Hightower and G. Borriello, “A Survey and Taxonomy of Location Systems for Ubiquiitous Computing,” Tech. Rep., University of Washington, Seattle, WA, Aug. 2001.

[14] J. Hightower, G. Borriello, and R. Want, “SpotON: An Indoor 3D Location Sensing Technology Based on RF Signal Strength,” Tech. Rep., University of Washington and Xerox Palo Alto Research Center, Seattle, WA and Palo Alto, CA, Feb. 2000.

[15] H. Clampitt, “The RFID handbook,” May 2006, http://www.rfidhandbook.blogspot.com/.

[16] “Radio Frequency Identification,” Aug. 2006, http://en.wikipedia.org/wiki/Rfid.

[17] P. J. Sweeney, *RFID Basics for Dummies*, New York: Wiley Publishing, Inc, 2006.

[18] M. Ward, R. Van Kranenburg, and G. Backhouse, "RFID : Frequency, standards, adoption and innovation," *JISC Technology and Standards Watch*, May 2006.

[19] "RFID The Frequencies," Aug. 2006, http://www.hightechaid.com/tech/rfid/rfid_frequency.htm.

[20] "Overview of RFID," Feb. 2007, http://www.productivitybyrfid.com/.

[21] "InfoLogix Announces HealthTrax RFID Asset Tracking Software for Hospital Mobile Assets Management," Aug. 2006, http://www.bbwexchange.com/publications/page139598309.asp.

[22] L. Kakadiaris and D. Metaxas, "Model Based Estimation of 3D human Motion," *2000 IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 22, no. 12, pp. 1453–1459, Dec. 2000.

[23] C. Sminchisescu, A. Kanaujia, Z. Li, and D. Metaxas, "Discriminative Density Propagation for 3D Human Motion Estimation," *2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05)*, vol. 1, pp. 390–397, 2005.

APPENDIX A

THE NUMERICAL RESULTS OF SCENARIOS

Table IX. Changed Probabilities of Scenario 1

	Result(Most)	Result(Farthest)	Difference
sample 1	57.70	67.20	9.50
sample 2	58.42	66.57	8.15
sample 3	59.14	65.94	6.80
sample 4	59.86	65.32	5.46
sample 5	60.58	64.69	4.11
sample 6	61.30	64.06	2.76
sample 7	62.02	63.44	1.42
sample 8	62.74	62.81	0.07
sample 9	62.24	62.18	0.06
sample 10	61.60	61.56	0.04
sample 11	60.96	60.93	0.03
sample 12	60.32	60.30	0.02
sample 13	59.68	59.67	0.01
sample 14	59.04	59.05	0.01
sample 15	58.40	58.42	0.02
sample 16	57.76	57.79	0.03

- **Optimal Traveling Route of Scenario 1**
  - $Result(Most)$: Sample 1 to 8 : subection 2/ $3 \Rightarrow 4 \Rightarrow 1$

Sample 9 to 16 : subsection 2/ $4 \Rightarrow 3 \Rightarrow 1$

$\circ$ $Result(Farthest)$: Sample 1 to 16 : subsection 4/ $2 \Rightarrow 3 \Rightarrow 1$

Table X. Changed Probabilities of Scenario 2

	Result(Most)	Result(Farthest)	Difference
sample 1	55.78	58.54	2.76
sample 2	58.54	61.30	2.76
sample 3	61.30	64.06	2.76
sample 4	64.06	66.82	2.76
sample 5	66.82	69.58	2.76
sample 6	69.58	72.34	2.76
sample 7	72.34	75.10	2.76
sample 8	75.10	77.86	2.76
sample 9	77.86	80.62	2.76
sample 10	78.98	83.38	4.40
sample 11	78.82	86.14	7.32
sample 12	78.66	88.90	10.24
sample 13	78.50	90.66	12.16
sample 14	78.34	91.94	13.60

- **Optimal Traveling Route of Scenario 2**
  - $Result(Most)$: Sample 1 to 9 : subection 2/ $3 \Rightarrow 4 \Rightarrow 1$

    Sample 10 to 14 : subsection 2/ $1 \Rightarrow 3 \Rightarrow 4$
  - $Result(Farthest)$: Sample 1 to 12 : subsection 4/ $2 \Rightarrow 3 \Rightarrow 1$

    Sample 13 to 14 : subsection 4/ $2 \Rightarrow 1 \Rightarrow 3$

Table XI. Changed Probabilities of Scenario 3

	Result(Most)	Result(Farthest)	Difference
sample 1	61.30	64.06	2.76
sample 2	61.30	62.74	1.44
sample 3	61.30	61.42	0.12
sample 4	60.12	60.10	0.02
sample 5	58.77	58.78	0.01
sample 6	57.43	57.46	0.04

- **Optimal Traveling Route of Scenario 3**
  - $Result(Most)$: Sample 1 to 3 : subection 2/ $3 \Rightarrow 4 \Rightarrow 1$

    Sample 4 to 6 : subsection 2/ $4 \Rightarrow 3 \Rightarrow 1$
  - $Result(Farthest)$: Sample 1 to 6 : subsection 4/ $2 \Rightarrow 3 \Rightarrow 1$

Table XII. Changed Probabilities of Scenario 4

	Result(Most)	Result(Farthest)	Difference
sample 1	64.49	64.39	0.10
sample 2	64.42	64.33	0.11
sample 3	64.36	64.26	0.10
sample 4	64.18	64.20	0.02
sample 5	62.74	64.13	1.39
sample 6	61.30	64.06	2.76

- **Optimal Traveling Route of Scenario 4**
  - $Result(Most)$: Sample 1 to 3 : subection 2/ $4 \Rightarrow 3 \Rightarrow 1$

Sample 4 to 6 : subsection 2/ $3 \Rightarrow 4 \Rightarrow 1$

∘ $Result(Farthest)$: Sample 1 to 6 : subsection 4/ $2 \Rightarrow 3 \Rightarrow 1$

Table XIII. Changed Probabilities of Scenario 5

	Result(Most)	Result(Farthest)	Difference
sample 1	53.70	60.56	6.86
sample 2	54.42	60.02	5.60
sample 3	55.14	59.47	4.33
sample 4	55.86	58.92	3.06
sample 5	56.58	58.38	1.80
sample 6	57.30	57.83	0.53
sample 7	58.02	57.28	0.74
sample 8	58.74	56.73	2.01
sample 9	58.24	56.19	2.05
sample 10	57.60	55.64	1.96
sample 11	56.96	55.09	1.86
sample 12	56.32	54.55	1.77

- **Optimal Traveling Route of Scenario 5**

∘ $Result(Most)$: Sample 1 to 8 : subection 1/ $3 \Rightarrow 4 \Rightarrow 2$

Sample 9 to 12 : subsection 1/ $4 \Rightarrow 3 \Rightarrow 2$

∘ $Result(Farthest)$: Sample 1 to 12 : subsection 4/ $1 \Rightarrow 3 \Rightarrow 2$

Table XIV. Changed Probabilities of Scenario 6

	Result(Most)	Result(Farthest)	Difference
sample 1	51.46	52.18	0.72
sample 2	54.38	55.00	0.62
sample 3	57.30	57.83	0.53
sample 4	60.22	60.65	0.43
sample 5	63.14	63.48	0.34
sample 6	66.06	66.31	0.25
sample 7	68.98	69.13	0.15
sample 8	71.90	71.96	0.06
sample 9	74.82	74.79	0.03
sample 10	77.74	77.61	0.13
sample 11	80.66	80.44	0.22
sample 12	83.58	83.26	0.32
sample 13	85.89	86.09	0.20
sample 14	87.56	88.92	1.36

- **Optimal Traveling Route of Scenario 6**
  - $Result(Most)$: Sample 1 to 12 : subection 1/ $3 \Rightarrow 4 \Rightarrow 2$

    Sample 13 to 14 : subsection 1/ $4 \Rightarrow 3 \Rightarrow 2$
  - $Result(Farthest)$: Sample 1 to 14 : subsection 4/ $1 \Rightarrow 3 \Rightarrow 2$

Table XV. Changed Probabilities of Scenario 7

	Result(Most)	Result(Farthest)	Difference
sample 1	57.30	57.83	0.53
sample 2	57.14	56.51	0.63
sample 3	56.98	55.19	1.79
sample 4	55.64	53.87	1.77
sample 5	54.13	52.55	1.58
sample 6	52.63	51.23	1.40

- **Optimal Traveling Route of Scenario 7**
  - $Result(Most)$: Sample 1 to 3 : subection 1/ $3 \Rightarrow 4 \Rightarrow 2$

    Sample 4 to 6 : subsection 1/ $4 \Rightarrow 3 \Rightarrow 2$
  - $Result(Farthest)$: Sample 1 to 6 : subsection 4/ $1 \Rightarrow 3 \Rightarrow 2$

Table XVI. Changed Probabilities of Scenario 8

	Result(Most)	Result(Farthest)	Difference
sample 1	61.29	58.96	2.33
sample 2	61.06	58.73	2.33
sample 3	60.84	58.51	2.33
sample 4	60.50	58.28	2.22
sample 5	58.90	58.05	0.85
sample 6	57.30	57.83	0.53

- **Optimal Traveling Route of Scenario 8**
  - $Result(Most)$: Sample 1 to 3 : subection 1/ $4 \Rightarrow 3 \Rightarrow 2$

Sample 4 to 6 : subsection 1/ $3 \Rightarrow 4 \Rightarrow 2$

$\circ$ $Result(Farthest)$: Sample 1 to 6 : subsection 4/ $1 \Rightarrow 3 \Rightarrow 2$

APPENDIX B

MATERIALS FOR SCENARIO 3 AND 4

Table XVII. Changed Probabilities of Scenario 3

	Subsection 1	Subsection 2	Subsection 3	Subsection 4
sample 1	5 %	50 %	25 %	20 %
sample 2	5 %	52 %	23 %	20 %
sample 3	5 %	54 %	21 %	20 %
sample 4	5 %	56 %	19 %	20 %
sample 5	5 %	58 %	17 %	20 %
sample 6	5 %	60 %	15 %	20 %

Table XVIII. Changed Probabilities of Scenario 4

	Subsection 1	Subsection 2	Subsection 3	Subsection 4
sample 1	5 %	40 %	25 %	30 %
sample 2	5 %	42 %	25 %	28 %
sample 3	5 %	44 %	25 %	26 %
sample 4	5 %	46 %	25 %	24 %
sample 5	5 %	48 %	25 %	22 %
sample 6	5 %	50 %	25 %	20 %

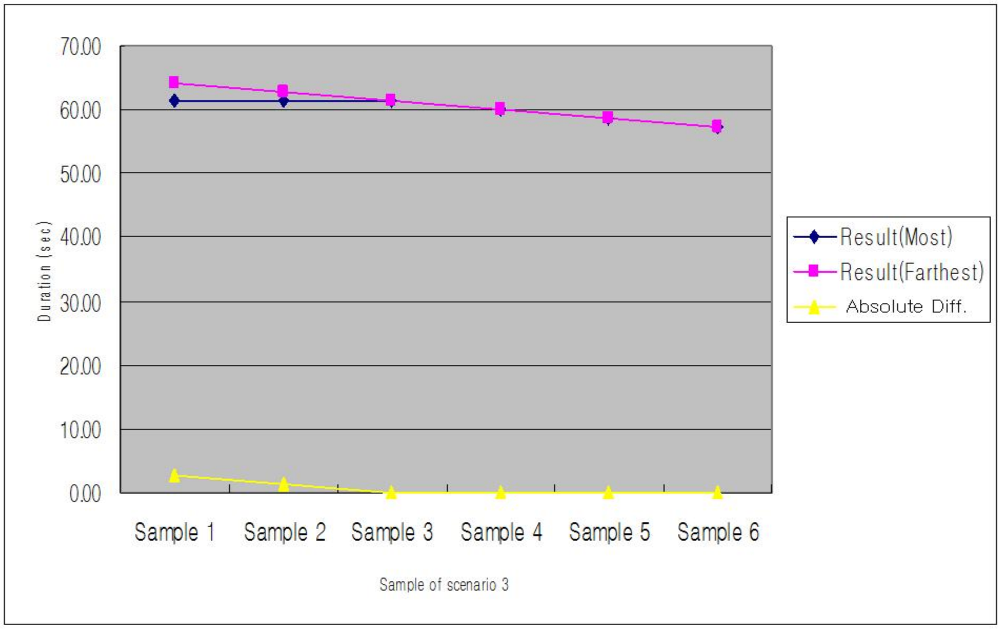

Fig. 19. Search Time to Find the Tag for Scenario 3

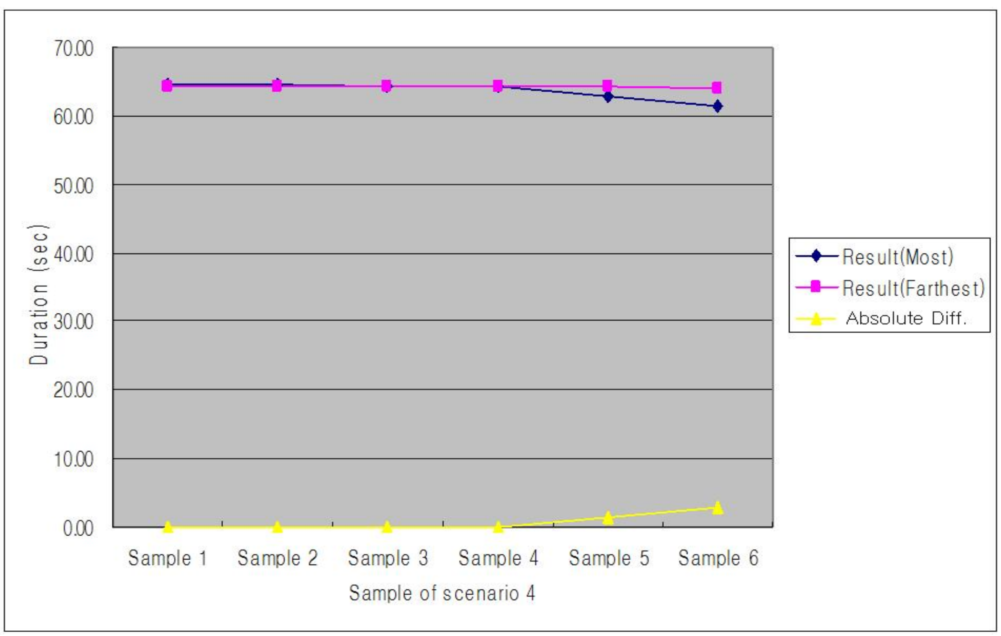

Fig. 20. Search Time to Find the Tag for Scenario 4

APPENDIX C

MATERIALS FOR SCENARIO 7 AND 8

Table XIX. Changed Probabilities of Scenario 7

	Subsection 1	Subsection 2	Subsection 3	Subsection 4
sample 1	50 %	5 %	25 %	20 %
sample 2	52 %	5 %	23 %	20 %
sample 3	54 %	5 %	21 %	20 %
sample 4	56 %	5 %	19 %	20 %
sample 5	58 %	5 %	17 %	20 %
sample 6	60 %	5 %	15 %	20 %

Table XX. Changed Probabilities of Scenario 8

	Subsection 1	Subsection 2	Subsection 3	Subsection 4
sample 1	40 %	5 %	25 %	30 %
sample 2	42 %	5 %	25 %	28 %
sample 3	44 %	5 %	25 %	26 %
sample 4	46 %	5 %	25 %	24 %
sample 5	48 %	5 %	25 %	22 %
sample 6	50 %	5 %	25 %	20 %

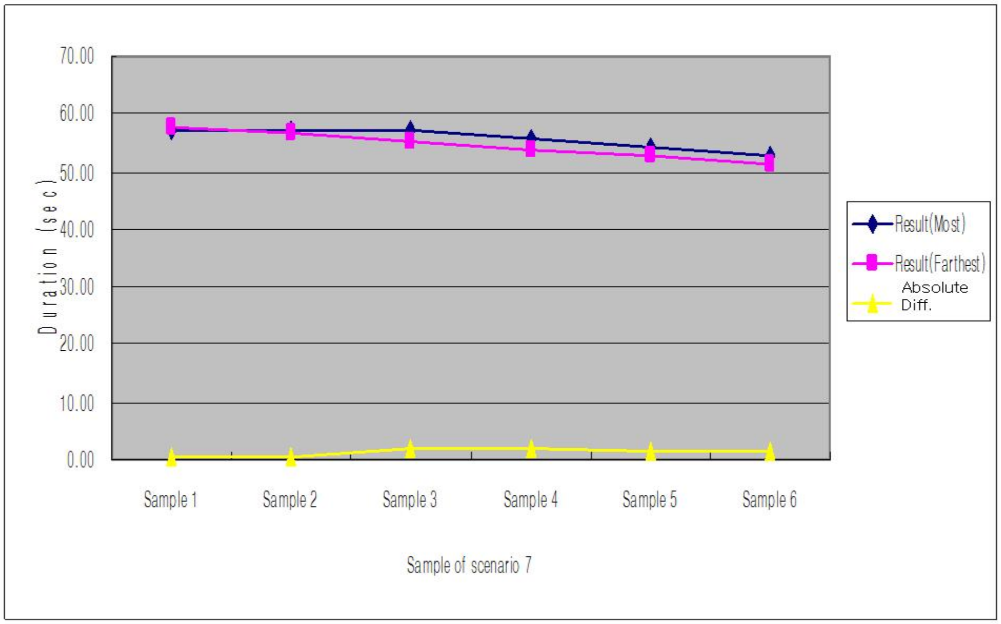

Fig. 21. Search Time to Find the Tag for Scenario 7

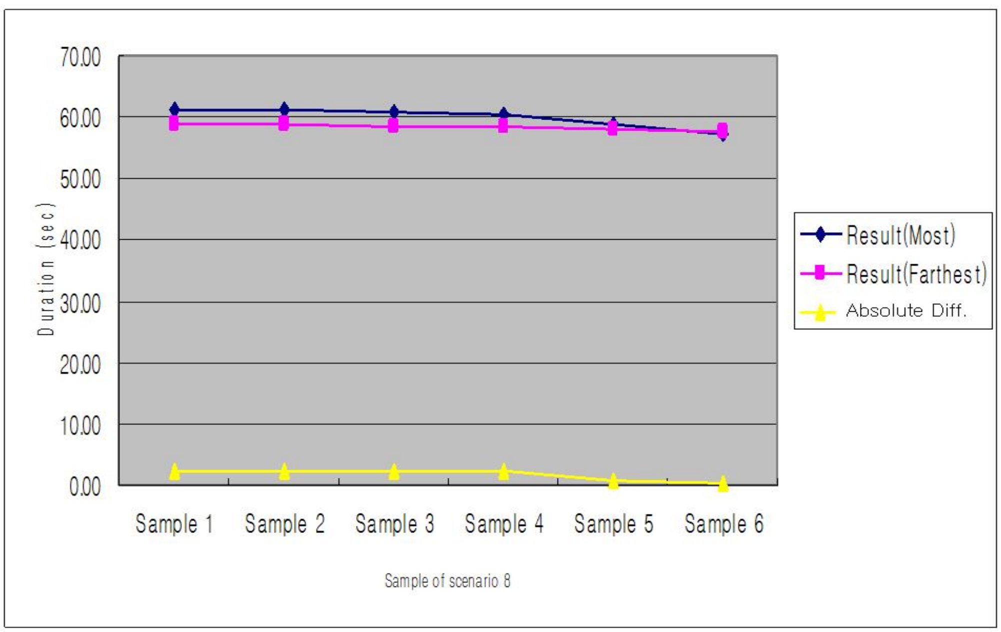

Fig. 22. Search Time to Find the Tag for Scenario 8

APPENDIX D

PROBABILITY RESOURCES APPLIED IN SCENARIO 11

Table XXI. Resource 1

subsection 1	subsection 2	subsection 3	subsection 4	subsection 5
1.85%	22.22%	18.52%	1.85%	1.85%
subsection 6	subsection 7	subsection 8	subsection 9	
1.85%	11.11%	25.93%	14.81%	

Table XXII. Resource 2

subsection 1	subsection 2	subsection 3	subsection 4	subsection 5
0.96%	24.04%	19.23%	0.96%	0.96%
subsection 6	subsection 7	subsection 8	subsection 9	
0.96%	9.62%	28.85%	14.42%	

Table XXIII. Resource 3

subsection 1	subsection 2	subsection 3	subsection 4	subsection 5
0.39%	27.56%	15.75%	0.39%	0.39%
subsection 6	subsection 7	subsection 8	subsection 9	
0.39%	3.94%	43.31%	7.87%	

Table XXIV. Resource 4

subsection 1	subsection 2	subsection 3	subsection 4	subsection 5
0.30%	21.28%	6.08%	0.30%	0.30%
subsection 6	subsection 7	subsection 8	subsection 9	
0.30%	3.04%	63.83%	4.56%	

VITA

Name: Gak Gyu Kim

Address: Department of Industrial and Systems Engineering
Zachry Engineering Center, Texas A&M University
College Station, TX 77843-3131

Email Address: keyperson78@neo.tamu.edu

Education: B.E., Civil Engineering,
Korea Military Academy, 2001

M.S., Industrial Engineering,
Texas A&M University, 2007