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A HAZARDOUS AREA IDENTIFICATION MODEL USING AUTOMATED DATA COLLECTION (ADC) BASED ON BUILDING INFORMATION MODELLING (BIM)

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ABSTRACT: A considerable number of construction disasters occur on pathways. Safety management is usually performed on construction sites to prevent accidents in activity areas. This means that the safety management level of hazards on pathways is relatively minimized. Many researchers have noted that hazard identification is fundamental to safety management. Thus, algorithms for helping safety managers to identify hazardous areas are developed using automated data collection technology. These algorithms primarily search for potential hazardous areas by comparing workers' location logs based on a real-time location system and optimal routes based on BIM. Potential hazardous areas are filtered by identified hazardous areas and activity areas. After that, safety managers are provided with information about potential hazardous areas and can establish proper safety countermeasures. This can help to improve safety on construction sites.

Keywords: safety management, hazard area identification, automated data collecting (ADC), real-time locating system (RTLS), building information modeling (BIM)

1. INTRODUCTION

The construction industry includes more risk factors than other industries because construction sites have their own characteristics (Schatterman et al. 2008, Hallowell and Gambatese 2009, Lee et al 2009a, Kim 2010). In addition, construction accidents can be divided into those occurring during working and those occurring whilst moving to the working space. Korea Occupational Safety and Health (KOSHA)'s fatal accident reports (2001~2003) indicate that 20% of accidents in the construction industry occurred when laborers were moving or are related to movement (Lee 2005). Risks on the movement path are significantly different from risks in working spaces due to performing other works, piling risky materials and the existence of openings.

On construction sites, trade based safety management is performed by focusing on work spaces. For this reason, the management level for moving processes or paths is lower than work spaces. The dynamic changes within construction sites also makes it hard for safety managers to identify the generation and extinction process of hazards on paths (Sacks et al. 2009).

The British Standard Institution (1996) suggested a four-step approach to safety management that consists of hazard identification, risk assessment and analysis, risk selection and control, and maintenance. The "Risk assessment and analysis" step is one of the effective methods to manage hazards. Although safety plans are established and performed, hazards can occur that were left out of planning steps because of the dynamic state of construction sites. Unidentified hazards negate the "Risk assessment and analysis" step; risks cannot be assessed and control measures cannot be developed and implemented if those involved are not aware of the hazards in the first step (Carter and Smith 2006).

Carter and Smith (2006) suggest that the hazard identification ratio of general projects is 66.5%. This means that the unidentified hazard ratio is higher than 30%. Although unidentified hazards are a factor in triggering accidents, it is not economical and efficient for safety management to increase the level of identification or the number of safety managers or both to identify all the hazards. In order to perform safety management efficiently, there is a need to introduce automated methods to identify hazards.

There is much research on automated data collection (ADC) to improve the efficiency of safety management (Davidson and Skibniewski 1995, Navon and Kolton 2006, Navon and Kolton 2007). Navon and Kolton (2006, 2007) suggested a fall prevention model based on location tracking of safety equipment. In addition, Lee et al. (2009b) developed a labor location based system of warning laborers when they come near to hazardous areas. These studies were conducted to relieve the burden on safety managers and to perform safety management effectively.

From these backgrounds, the objective of this study is to develop a model that automatically identifies hazards on the movement paths through labor location tracking. The model identifies hazardous areas using deviation between laborers' location logs and optimal routes. By making a comparison between existing hazardous areas and work spaces, previously unidentified hazardous areas can be identified and then can be used to perform efficient safety management.

Before starting a construction project, safety plans are established at the site level. Considering the dynamic conditions of a construction site, there can be hazardous areas which are not included in the safety plans. To eliminate hazardous areas on optimal routes, the rest of this study is organized as follows. A summary of the state of the art on automated data collection (ADC) is presented. From this, the implications and limitations of current research are extracted to be applied to safety management. Supported by this work, assumptions for developing algorithms are suggested and an ADC based hazard identification model is established. The suggested model has detailed algorithms, DBs, and modules. The components of the model will be examined further in the "Hazard Identification Model" section.

2. Preliminary Study

There has been much research on safety management and hazard identification. This section briefly discusses three parts; definitions of risk and hazard, research on hazard identification and ADC on the literature.

2.1 Definitions

There are many definitions of risks and hazards. In the context of Occupational Safety and Health Administration (OSHA), risk can be defined as the integration of both the likelihood and the consequences of hazards. Jannadi and Almishari (2003) also defined risk as a measure of the probability, severity and exposure of all the hazards of an activity. Baradan and Usmen (2006) defined a hazard as the potential for an activity or condition to produce harmful effects. The Health and Safety Commission (1995) also defined a hazard as the probability of harm. Other researchers described a hazard as the possibility of unplanned or undesired events such as fatalities or non-fatality accidents.

In this paper, the three terms are defined as follows:

- Risk is the combination of the frequency and severity of undesirable events.
- A hazard is defined as an inherent characteristic of an activity or situation that has the potential of causing an undesirable event that has consequent injuries or fatalities.

2.2 Hazard Identification

Many researchers have studied the identification of hazards. As shown Fig. 1, hazards to laborers can be broadly divided into activity-oriented and space-oriented. They also follow a course of generation and elimination over time (An 2007).

Other researchers developed some methods that assessed risks related to activities or dealt with spaces as hazardous areas (Schatterman et al., 2008, Hallowell and Gambatese, 2009). Sacks et al. (2009) calculated the probability and time of exposure to the hazard. Furthermore, it was represented in a 4D model to be visualized.

The research mentioned above focused on work spaces. Studies on finding hazardous areas when a laborer moves to a work space, or simply moves, have rarely been performed.

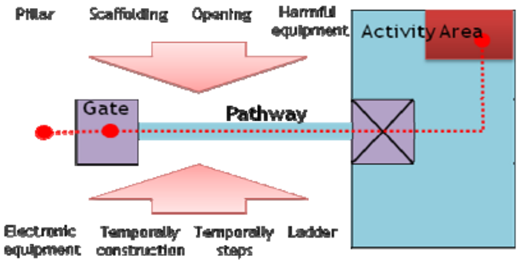


Fig 1. Classification of Hazardous Area

2.3 Automated Data Collection (ADC)

Hazard identification is an essential step in safety management. However, it is not efficient for a small number of safety managers to search every space to find hazardous areas; this may not get adequate performance. Thus, this study selects a method that analyzes laborers' location information and uses ADC. It notifies safety managers of spaces with a high probability of being hazardous.

Fortunately, advances in information technology have provided solutions to the construction industry. There is research that applies information technology to the construction industry. In the past, ADC was used in the manufacturing industry. It has also been utilized in the construction industry in recent years. When ADC was in the early stages of being used in the construction industry it was applied to general project management and material management (Blakey 1990, Rasdorf and Herbert 1990, Davidson and Skibniewski 1995).

Oloufa et al. (2003) developed a global positioning system (GPS) based model to track materials. Lu et al (2009) suggested that various resources could be tracked by using GPS and radio frequency identification (RFID). They also asserted that the model is economical. However, considering indoor conditions in terms of the research scope, it is difficult to use GPS indoors where there is much more wave propagation loss than in outdoor conditions. Moreover, GPS used indoors cannot be expected to attain accuracy of location determination.

The possibility of using RFID in the construction industry has been suggested in various fields; labor attendance management and material management (Choi 2004, Jaselskis and El-Misalami 2003, Dziadak et al. 2009). There is another example of applying RFID to safety management. Lee et al (2009) suggested a laborer's location-based model warning when laborers enter hazardous areas. There is another safety management model which searches for hazards through activities and dangerous edges and facilitates fall prevention equipment (Navon and Kolton 2006, Navon and Kolton 2007).

There are so many factors that affect safety; it is difficult for safety managers to handle all these factors, which, moreover, is not cost effective. It is advantageous to introduce ADC at management level.

3. Hazard Identification Model

Through the literature reviews, some technologies are examined to be applied to this study. This section develops algorithms based on laborers' location, identified hazardous areas, work spaces and optimal routes.

3.1 Assumptions

The four assumptions made to develop a hazardous area identification model are as follows:

(1) When laborers move to where they want to go, they have a tendency to move along an optimal route to minimize physical work.

(2) "Optimal Route" means the shortest path between two places where laborers wants to move (Rilett and Park 2009).

(3) In the case of obstacles (activities, material, hazards etc.) on an optimal route, laborers deviate from the route.

(4) This model deals with hazardous areas on optimal routes only. It does not deal with hazardous areas in other places.

3.2 Conceptual Model

The conceptual model suggested in this study is shown in fig 2. When laborers move to work spaces, they select the shortest path. If the laborer's actual path deviates from the optimal route, there may be an obstacle hindering the laborer's movement along the path. These obstacles can be piled up materials, working space, or hazardous areas. If the deviation between the laborer's actual path and the optimal route is calculated by using a real-time location system (RTLS) and ADC, safety managers can easily identify hazardous areas.

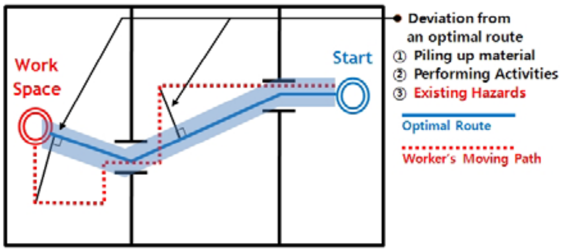


Fig 2. Conceptual model for hazardous area identification

3.3 Framework for the Hazard Identification Model

As shown fig 3, the framework suggested in this study consists of six databases and three modules. The role of each module is to have date input from related modules and databases, process the data and send it to the next step of modules or databases. The unidentified hazardous area identification module searches for spaces with a high possibility of hazards, which are filtered by the filtering hazardous area module. Filtered hazardous areas are extracted and represented in the monitoring and output generation module. All of these results are stored to reflect the generation and elimination process of hazards over time.

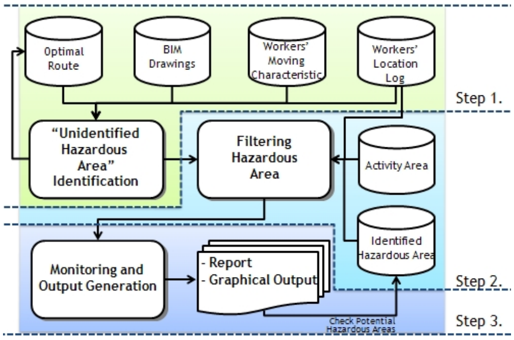
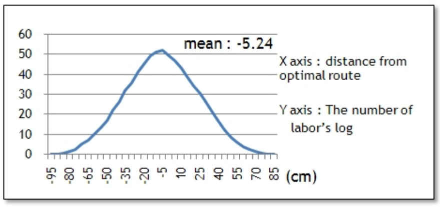


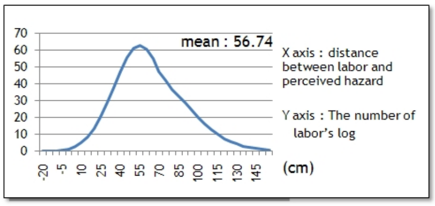
Fig 3. Framework of hazardous area identification

The following section explains the six databases; the three modules will be explained in the next section.

- BIM drawings: its role is to provide basic information to the system. It is a parametric and object-oriented system. These drawings extract objects to check the interference in the process of determining the optimal route. They also represent coordination of other databases.
- Optimal route: The node concept is introduced to determine an optimal route. A node in this study is defined as a passing point when laborers move from space to space. Doors, stairs, hoists and elevators can be nodes. Based on the node concept, the optimal route is the shortest path between one node and another node.
- Workers' moving characteristic: As figure 4. Indicates, there are two kinds of data; the first data represents the distance from the optimal route when laborers move along the route. The second data demonstrates the distance from the hazard when laborers recognize it. To obtain the results, two experiments were examined. 37 laborers with helmet-mounted RTLS equipment were examined to calculate the first data.



(a) Distance from optimal route



(b)Distance between labor and perceived hazard

Fig 4. Laborers' moving characteristics

In this experiment, more than 95% of the locations logged were within the range of -54.28cm to +50.66cm (- means left side and + means right side). To apply these results to the system, the right and left width is determined as ±50cm. the second data follows as the first experiment. The mean of the results is 56.74cm. It is used in the following algorithms. To summarize these experiments, the laborers are usually in the range of 50cm from optimal routes. If they recognize a hazard, they would be out of that range.

- Workers' location log: The location tracking method used in this study is chirp spread spectrum (CSS) based RTLS. As shown in figure 5, the RTLS reader receives signals from a tag attached to the laborer. These signals are sent to base-stations on each floor. All the information generated in this process is stored to be used in the unidentified hazardous area module and the filtering hazardous area module.

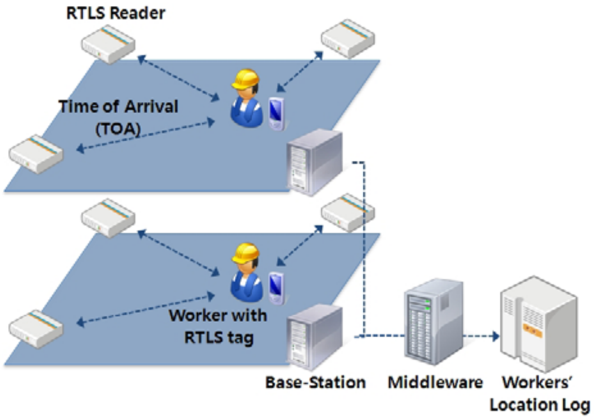


Fig 5. Real-time tracking location system

- Activity area: This stores areas where work is accomplished over time. This data and the BIM drawings are combined, and are used in the filtering hazardous area algorithm.
- Identified hazardous area: this includes three types of data: hazardous areas searched by safety managers; hazardous areas generated by the unidentified hazardous area identification algorithm and the filtering hazardous area algorithm; and eliminated hazardous areas over time.

3.4 Detailed Algorithms

Based on the six databases mentioned above, this section will suggest detailed algorithms for each module.

3.4.1 Unidentified hazardous areas

The algorithm identifying previously unidentified hazardous areas consists of three parts. The first part extracts node elements and determines optimal routes. The second part calculates laborers' routes using RTLS. Finally, the algorithm maps the extracted optimal routes and laborers' routes. It also recognizes hazardous areas if the deviation between these routes is more than a certain level (50cm).

Figure 6 shows how optimal routes are calculated. Some elements which could function as nodes have been extracted. After connecting nodes in straight lines, the algorithm checks the interference between other elements. Then, lines that are not interfered with are extracted and the list of optimal routes is generated. It is mapped on each of the floor plans.

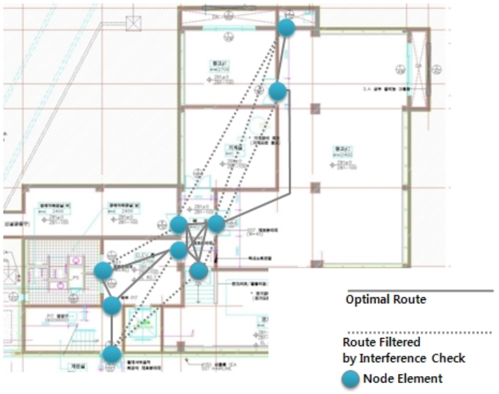


Fig 6. Example of determining optimal route

To find unidentified hazardous areas, first of all optimal routes and laborers' routes are mapped on each of the floor plans. Based on this information, the algorithm finds logs that stray from the optimal routes. It connects the logs and identifies a hazardous area using a space made by connected logs. All of these processes are shown in figure 7.

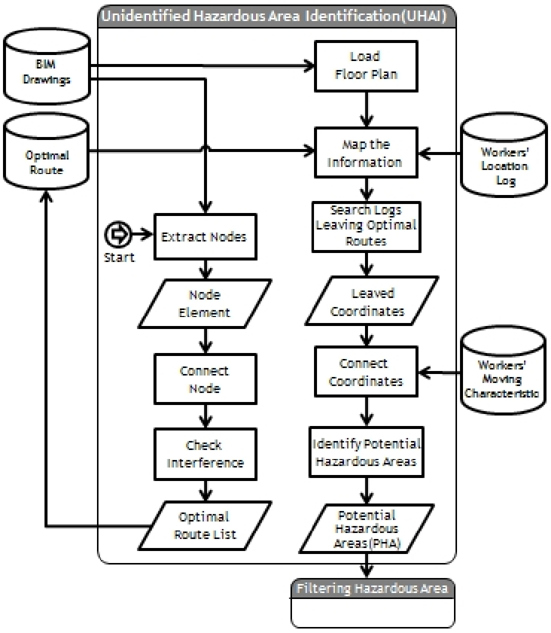


Fig 7. Unidentified hazardous area identification

3.4.2 Filtering hazardous areas

This algorithm includes two steps. The first step filters automatically hazards that are eliminated over time. The next step filters potential hazardous areas for a second time.

First of all, the algorithm compares the coordination of identified hazardous area and laborers' logs. If there is an intersection between these coordination sets, the intersection area could be regarded as a safe area where laborers attempt an approach. In this case, the algorithm lifts the area being set as a hazardous area and the results are stored in the identified hazardous area database.

Potential hazardous areas extracted in the unidentified hazardous area identification module can be defined as the union of unidentified and identified hazardous areas and work spaces.

To provide proper information to safety managers, identified hazardous areas and work spaces are filtered from potential hazardous areas. By doing this, the algorithm results in a set of twice-filtered potential hazardous areas. Information about the area is sent to the monitoring and output generation module. The process mentioned above is represented in figure 8.

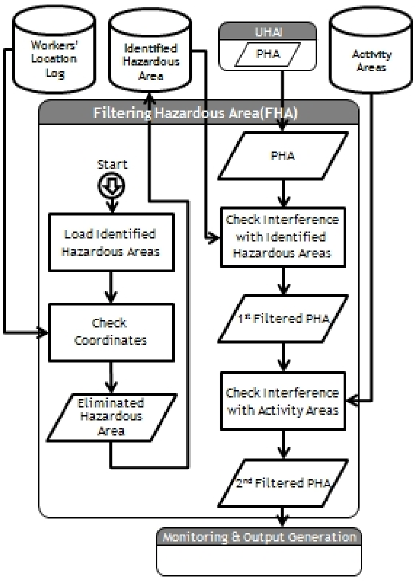


Fig 8. Filtering hazardous area

3.4.3 Monitoring and output generation

The detailed algorithm of the monitoring and output generation module is as shown in figure 9. This module starts by receiving the twice-filtered potential hazardous areas. These areas are mapped on a BIM drawing and the coordinates of the areas are extracted. Based on the coordinates, the algorithm generates reports including graphical outputs, coordinates of hazardous areas, laborers coming close to the hazardous areas, and related activities.

From these results, safety managers can identify where potential hazardous areas are. They check areas with high potential hazard risks. They judge whether the areas are risky or not. If some areas are identified as risk areas, they are stored in the identified hazardous area database. The database updates the generation and elimination process of hazardous areas over time. The filtering hazardous area module removes the eliminated hazardous areas and the monitoring and output generation module produces the hazardous areas. This means that these algorithms reflect the construction characteristics of changing hazardous areas over time.

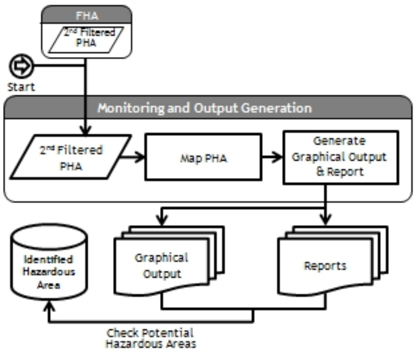


Fig 9. Monitoring and output generation

4. Model Development and Validation

The purpose of this section is to develop and validate the model suggested. Before system development, the protocol and devices should be defined. The detailed contents of these are shown as table 1 and table 2.

Table 1. Definitions of system protocol

Data	Project ID	Tag ID	Coordination		Floor	Time
			X	Y		
Byte	2	4	4	4	1	7

Table 2. Reader and tag

	Reader	Tag
Function	• Determining distance to tags • Sending data to base-station	• Tracking location
Characteristic	• Cortex-M3 of ARM corporation • 72MHz • 128KB flash, 20KB RAM • Battery based	• Processor : TI MSP430 • RF Transceiver : NA5TR1 • Transmission distance : 450m
Picture		

A two step approach is taken to develop the system. First, BIM property values are extracted using a developer's kit. In this study, ArchiCAD 13, which is an easy to use tool for developing applications, is used and C++ is selected to program. Secondly, three modules are coded by using Visual Studio 6.0 and C#.

Site validation was executed to test the system performance and the accuracy of hazard identification. The test site was an academic building with five stories and 5000m^2 gross floor areas. The test was carried out on the basement and ground floor. Four RTLS readers were set in the corners of each floor and four laborers with tags were observed.

The results of the test are presented in table 3. The system found five hazardous areas. Four of these were real hazards and one was a system error.

Table 3. Results of site test

Hazardous area ID	X axis (mm)	Y axis (mm)	Hazard	Description
00-00-01-001	122020	4040	○	Piling hazard materials
00-00-01-002	134500	9210	○	Deficiency of electric wire protection
00-00-02-001	8830	4830	○	Piling hazard materials
00-00-02-002	9050	2670	×	-
00-00-02-003	140080	104820	○	Deficiency of fall protection (opening)

5. CONCLUSIONS

Currently safety management is executed to focus on the work space. Because of the inherent risks in the construction industry, there are hazards on construction sites, not only in workspaces but also on pathways.

This study develops a hazardous area identification model using RTLS and ADC. Before developing the model, four assumptions were suggested. Then, the hazardous area identification framework, consisting of six databases and three modules, were developed. In this phase, the information flows and functions of each of the databases were defined. All the input and output data of the modules were represented. Finally, the detailed algorithms of the unidentified hazardous area identification module, the filtering hazardous area module, monitoring and output generation module were suggested. Based on this process, the hazardous areas were identified by the deviations between the laborers' real paths and the optimal routes. The filtering hazardous area module reduced the range of possible hazardous areas to improve safety management efficiency.

Because of wave propagation, one of the limitations of RTLS, laborers' real location does not accurately correspond with the result of RTLS. This study assumes that the tracking location technology will be fully developed in the near future. If there are more accurate methods, hazardous areas can be more accurately identified.

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