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Safety Management System Prototype Based on BIM with RTLS

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ABSTRACT: In past projects, the main goal has been to enhance efficiency by reducing cost and time. However, considering the current condition of safety management in many construction companies, it can be confirmed that safety management has not been a top priority for a long time. Current safety management, which is based on safety standards and rules, is very ineffective and only emphasizes management after an incident. As well, although fewer accidents occur compared to the past, because construction projects are increasingly large in scale and complex, these accidents tend to be more serious and involve greater monetary loss. Furthermore, as the severity of these accidents increases, so does the possibility of fatalities. Therefore, improving safety management is essential. This study proposes an effective program for safety management, focusing on the processes to connect studies and systems, and the basic techniques required for program development. To realize this program, technical tools are suggested, including systems such as BIM (Building Information Modeling); additionally, the coordination of other systems such as an RTLS, a server, and an alarm system is proposed.

Keywords: Construction Safety Management, Building Information Modeling, Real-Time Locating System, Server, Alarm System

1. INTRODUCTION

1.1 Objectives

While the primary goal of construction projects is effective cost and time management, construction companies have began to focus on a new goal: safety management. Considering both domestic and foreign construction projects, although the frequency of accidents has been reduced, these accidents are becoming more serious, and even fatal, as construction projects become larger and more complicated. Therefore, effective safety management is even more crucial.

However, safety management practices need to be updated and improved to function effectively in the current context. For cost management and process management, there are various management programs and systems. On the other hand, current safety management merely focuses on ex-post treatment based on knowledge such as safety standards and rules. This is not any different from safety management strategies deployed in the past.

Thus, this paper proposes a more effective safety management program. This program would potentially use a 3D BIM (Building Information Modeling) technique and a RTLS (Real Time Locating System). As well, it would apply other systems, such as data mart and an alarm system, in combination.

Ultimately, the main objective of this study is to propose an accident management program that can perform visualization of project risk factors and provide a tracking technique for employees. This study will also develop a more effective safety management approach that can collect and process data regarding safety management, connect with an alarm system, apply a 3D BIM technique, and analyze current safety appliances.

1.2 Project Scope and Methodology

This study will be limited to connecting related systems and concepts to develop a safety management program that utilizes location information based on BIM. As well, this study will define the protocol to develop the proposed system.

Furthermore, the actual conditions and problems related to current safety management will be examined, and the proposed program will be designed to solve these problems. Moreover, each concept and algorithm related to the BIM, RTLS, server, and alarm system will be defined, as these are integral to the development of the proposed program. Finally, the system architecture required for the realization of the program will be presented, and the concrete ways in which to connect each system and protocol will be described.

The stages of this study are shown in Fig. 1.

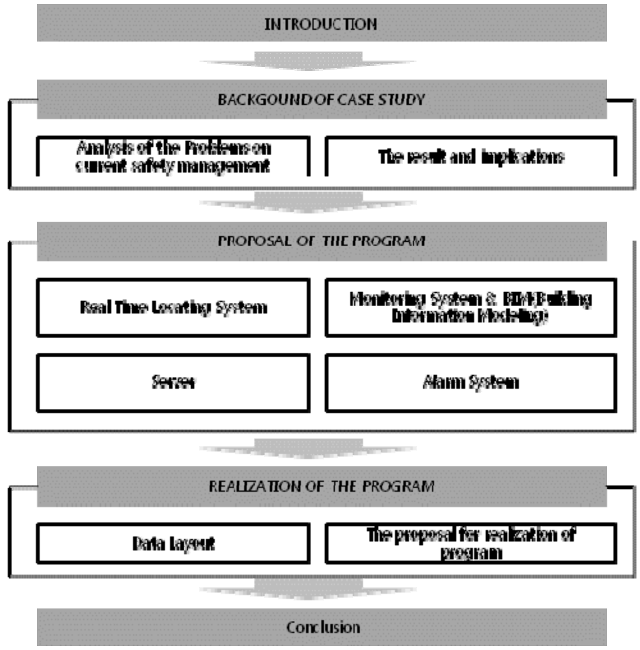


Figure 1. Stages of the study

2. BACKGROUND OF CASE STUDIES

2.1 Analysis of the problems in current safety management

Safety management at current construction project sites can be divided into two categories: hardware-like counterplans and software-like counterplans. For hardware-like counterplans, there are mainly technical approaches such as the improvement of construction laws and building safety facilities. On the other hand, software-like methods include safety education to cultivate a sense of security, and regulations made by strengthening the application of laws and insurance.

However, current safety management is not systematical, and it includes only fragmentary activities which have components that can be problematic. As a result, the safety management activities at current construction sites are not efficient.

Thus, we examined relevant previous studies to understand the current state of safety management.

Table 1. Literature review

Researchers	Materials	
John A. Gambatese et al (03,1997)	Title	Tool To Design For Construction Worker Safety
	Summary	This paper proposes a program that links the design and construction phases to improve construction worker safety.
Joe M. Wilson Jr et al. (02, 2000)	Title	Safety management : Problems Encountered AND Recommended Solutions
	Summary	This paper discusses the methods of safety

		management employed in a small- to medium-sized project in the northwestern United States.
D.P Fang et al (06, 2004)	Title	Benchmarking Studies on Construction Safety Management in China
	Summary	This paper identifies the key factors that influence safety management and develops a method for measuring safety management performance at construction sites.
Gregory Cater et al. (02,2006)	Title	Safety Hazard Identification on construction Projects
	Summary	This paper investigates and identifies the current levels of hazard in three U.K. construction projects.
Rafiq M. Choudhry (01, 2008)	Title	Safety Management in construction : Best Practices in Hong Kong
	Summary	This paper describes an exploratory study of site safety management in construction sites' environment.

2.2 The results and implications

After analyzing the current safety management activities in construction, based on the theses above, it is possible to derive the relevant problems and limitations. The problems of current safety management can be summarized into three parts.

First of all, current safety management activities are conducted predominantly based on satisfying the standard of test. That is to say, for the parts that can meet the standard and pass the tests, there are no afterward management activities. This is a temporary and fragmentary activity, not continuous and active management emphasizing precautionary action.

Second, there is no authentic counterplan and system for precautions, and the cost of dealing with an accident is extremely high. According to the Ministry of Labor (2006), the consequent economic loss, including the second-hand cost, is approximately 16 billion dollars (16,000 billion won). To put this into perspective, it would be possible to construct the Incheon International Airport with such a figure. Such a cost should not be ignored.

Third, all the sites use the same standard; this can cause problems. According to a characteristic of the building industry, all the sites cannot construct the same buildings. However, safety management at many construction sites does not reflect the specific characteristics of their own sites. This is because there are no concrete guidelines and standards for various special construction sites or conditions.

Besides these three problems, current safety management activities have mainly two limitations.

First, the authority of the safety manager is limited. This can be a problem when there is a conflict with other management activities. For example, among the management activities directed at process, time, cost, and safety, safety management is usually a lower priority. Indeed, while the management of process, time, and cost has long been prioritized in the building industry, safety management has not been regarded as important as these activities.

Next, the understanding of dangerous factors varies among managers. Compared to other management activities, safety management activities are not computerized, which is why the safety manager's ability is more influential on safety than on other factors. Therefore, the manager's expertise is the most important factor that must be changed in order to improve safety standards and create a systematic and comprehensive safety management.

Table 2. The results and implications

Problems	Limitations
□ only focused on meeting the standard of test □ it costs too much to deal with accidents □ same standard for the safety management of all construction sites	□ limited authority of safety managers □ different understanding of dangerous factors according to the expertise of safety managers □ pressure from other management activities

3. PROPOSED PROGRAM

3.1 Proposed Program

According to the results of the analysis above, a program is proposed that can solve the problems of safety management at construction sites. This program aims to complement the weak points of current safety management. It focuses on strengthening the precautionary function in order to avoid the current practice of ex-post treatment, and it enables safety management activities according to the safety manager's input of the characteristics of his/her work site. Additionally, it is possible to reflect site characteristics in the program by predicting and inputting the dangers before the planning and execution phases of a project, which is much different from safety management activity dependent solely on the ability of safety managers. This enables this program to be applied to any construction site, including special sites.

Table 3. Merits and demerits of the program

Merits	Demerits
□ can reflect the characteristics of many construction sites □ is active in preventing accidents □ real time safety	□ the question of the human rights of workers □ the ability of managers are reflected with the sites' characteristics

management activity to meet the standards, instead of perfunctory activities □ possibility of being applied to labor management programs	

The functions of this proposed program can be mainly divided into 4 techniques and systems. The RTLS (Real Time Locating System) is applied first, and it can locate workers at any time. Next, the BIM & Monitoring Systems are utilized to indicate the location of workers in 3D based on BIM. When workers are close to dangerous areas, the Alarming System is used to give a warning sign. Finally, a Server is necessary to support these systems and techniques and to process the algorithm. These programs are briefly described in Fig. 2., and they are described in more detail shortly.

- RTLS (Real Time Locating System)
  : Locates the workers
- BIM (Building Information Modeling) & Monitoring System
  : Indicates the location of workers in 3D based on BIM
- Alarming System
  : Provides a warning alarm when workers are close to dangerous areas
- Server
  : Stores and processes the data of the above systems

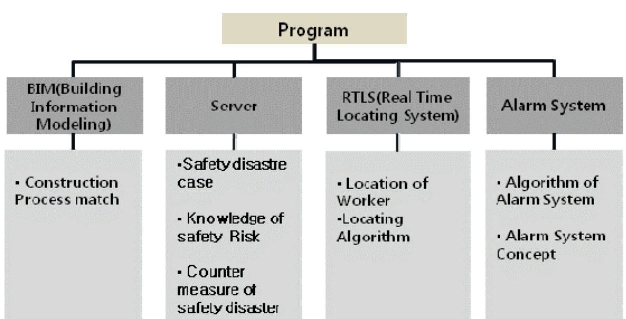


Figure 2. The proposed program

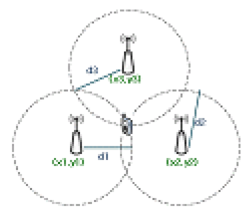
3.2 Real Time Locating System

The RTLS (Real Time Locating System) is mainly constituted of 3 types of hardware: Tag, Reader, and Locating Engine. While Tags and Readers are used to locate the workers, the Locating Engine obtains the location information. Because of this, RTLS is the most important technique to locate workers on a real-time basis.

Now, we will examine the composition, function, and locating methods. Tags are worn by workers, and many readers are established on each floor of the work site. Signals are sent continuously to these tags and readers; these signals enable the location of workers to be traced. Then, this traced location is sent to the engine and stored.

The tracing method used in this program is called Amplitude Triangulation (RSSI: Received Signal Strength Indication), as shown in Fig. 3. Workers always wear safety helmets with a tag fastened on it. More than 3 readers are established on the floor. With this approach, in which signals are sent between tags and readers when a worker's tag is in a reader's range, the real time location of workers can be captured. With these signals, the reader calculates the location of the worker using the intensity of the signal and the distance between reader and signal. The formula for calculating location is shown on the right hand side of Fig. 3.

These signals are also sent to the engine and stored and processed. The signals are applied to locating the algorithm using Multi-lateration in the engine, and this filtering technique, using a statistical method, is able to arrange the scattered locations of the workers. The algorithm is seen in Fig. 4.



$$L = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right)[dB]$$

L : path loss , d : distance , λ : wavelength

Figure 3. Location tracing concept

Using the algorithm pictured in Fig. 4., the coordinates of the workers' location, which are obtained from the tags and readers, are continuously stored and processed. Subsequently, the location of the workers is shown in 3D using the BIM and Monitoring System, which will be explained later.

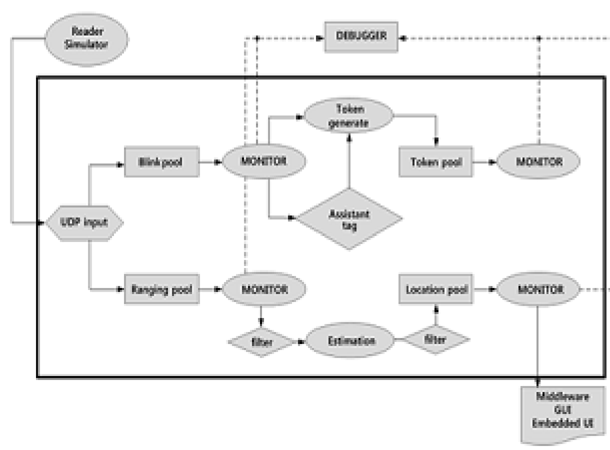


Figure 4. Locating algorithm

The above method is one of the location tracing techniques. The error tolerance of this method is very low, and it is possible to effectively find the exact location of workers. Also, it is suitable for construction sites with high potential for disasters and for sites that require sophistication. This is why this method is applied in the proposed program.

3.3 Monitoring System & BIM (Building Information Modeling)

After locating the workers using the location tracing technique, it is suggested that the Monitoring System &

BIM be used to apply the location to the BIM Tool and display the workers' locations in 3D. Consequently, the Monitoring System can be realized as a tool with the capacity to understand the exact situation in order to manage worker safety at construction sites.

The screen shown to the safety manager can be divided into two parts, which are the 3D screen based on the BIM Tool and the Monitoring System used to manage the safety of work sites. The monitoring screen enables the manager to monitor basic factors such as those described below.

The safety manager will input the location of workers (complex, building, floor), the process that is going on at that location, and what the workers are doing on the monitoring screen. With this approach, it is possible to predict possible dangers according to the specific characteristics of that construction site and to confirm appropriate preventative measures.

Accordingly, the Monitoring System is composed as seen in Fig. 5.

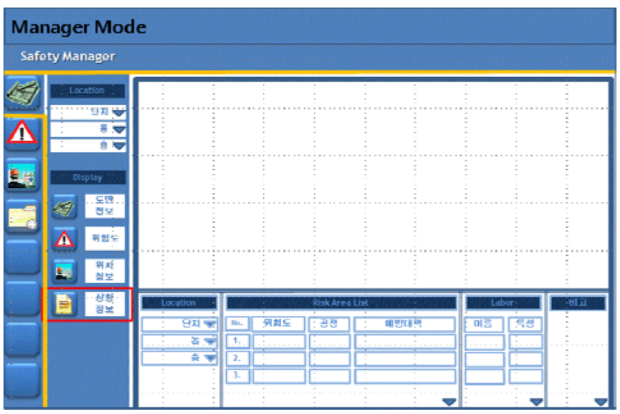


Figure 5. Monitoring system

Using this Monitoring System, a safety manager can determine and confirm the specific locations of workers, and he/she can select a worker viewed on the monitor.

Then, when a specific worker is chosen, the BIM Tool shows the location of that worker in 2D based on drafts and also in 3D. This screen is shown in Fig. 6.

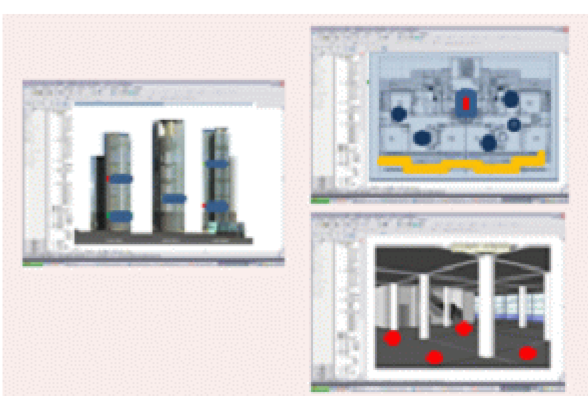


Figure 6. Tracing workers using 3D

3.4 Alarm System

We have explained the RTLS, and the Monitoring System and the BIM, which shows worker location in 3D. When these two systems are connected, it is only possible to locate workers. However, it is impossible to warn a worker when he/she is in a dangerous situation or close to a hazardous area. Therefore, an Alarm System should be connected to the two systems described above.

The proposed Alarm System is developed with a locating system for its hardware. An alarming device is put on the tags to warn workers when they are too close to a dangerous area.

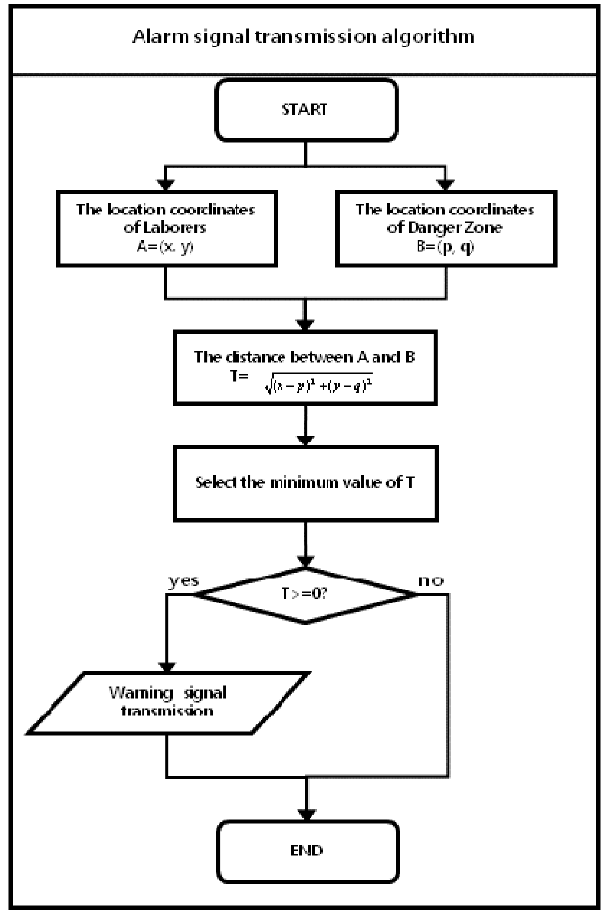


Figure 7. Algorithm of alarm system

An alarm module is also developed with the engine of the RTLS. This basic algorithm of the Alarm System, which is connected to the RTLS, can be seen in Fig. 7.

By locating the worker with the RTLS, the coordinates of the worker are calculated. This means that the coordinates of the worker are used to calculate the distance between the worker and the dangerous area. Then, based on this calculated distance, the minimum distance between the worker and the dangerous area is calculated. If this distance is under a certain standard, the alarm sounds, and if not, the alarm does not sound. This is connected to the RTLS. The concept behind this connection (i.e., RTLS and the Alarm System) is shown in Fig. 8.

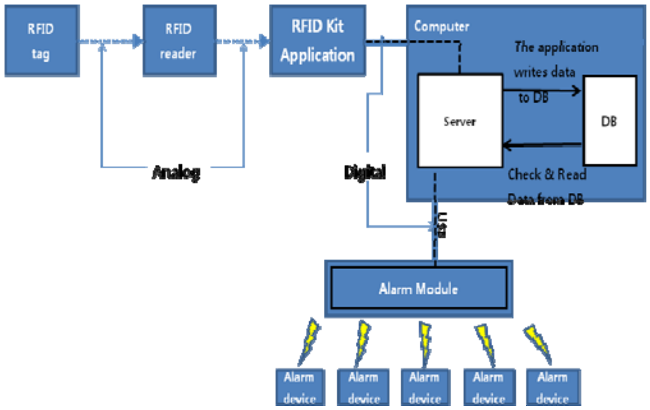


Figure 8. Alarm system concept

When the RTLS and Alarm System are connected, and a worker with a registered tag enters a work site, his/her location is captured by the reader. This location is then sent to the server, and the algorithm seen in Fig. 7 determines whether he/she is in a dangerous area or not. If the result shows that he/she is in a dangerous zone, the alarm signal is sent to the alarm module, and it is sent again to the safety helmet of the worker. Then, the worker's tag sounds the alarm.

3.5 Server

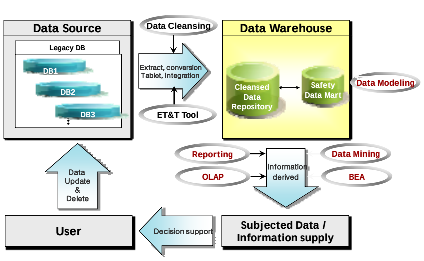
The server functions as an intermediary device that coordinates the RTLS, BIM & Monitoring System, and the data information from the Alarm System. The algorithms above are stored in the Server, which processes the data.

First of all, the data from the RTLS regarding the workers' coordinates is sent to the Server, and this data is processed from the algorithm and shown in 3D with the BIM Tool, which uses this processed data.

In the Alarm system, based on the coordinates of a worker's location, the dangerous condition of that worker is calculated using the Alarm algorithm. If the worker is in danger, a signal is sent to the alarm module in the Engine of the Server.

In the Monitoring System, the location information from the RTLS is sent to the Monitoring System, and the worker's location is shown in 3D.

While the flow and process of the data is explained above, each data are processed as shown below (see Fig. 9.). The gathered data are collected, changed, filtered, combined, and then stored at a data warehouse. Based on that data, Subjected Data/Information is sent to users through Data Mining, Reporting, and OLAP.



4. REALIZATION OF THE PROGRAM

4.1 Data Layout

To connect each system described above and develop the final program, the protocol between each system must be defined. Here, protocol refers to establishing a language which each system can understand. To define this protocol, many types of works are necessary, but among these, data layout is the most important and basic work. That is, the order of data processing should be defined. This order is shown in Fig. 10.

Let us examine the flow of the coordinate data of the RTLS. It is possible to obtain worker location using Tags and Readers, and this data is sent to the Server using a locating Engine. Then, this information is sent to the Monitoring System, and the safety manager can confirm the locations of workers. Furthermore, the Monitoring System (sends data?) to the BIM Tool, which displays the location of workers on a 3D screen by using an API (Application Program Interface). In the BIM's API, the coordinate data is shown in 3D using the defined protocol and algorithm.

Next, in the flow of the Alarm signal, data are also sent based on worker location. The coordinates of location are sent to the Server using the locating Engine. Then, the alarm algorithm in the Server is utilized to decide whether a worker is in danger or not. If a worker is in danger, the alarm signal is sent to the alarm module in the server. Then, the alarm module is sent again to the worker's tag, and the tag subsequently sounds the alarm. Conversely, if it is determined that the worker is in a safe area, the alarm does not sound.

Finally, using the Monitoring System, the safety manager can obtain the dangerous factors and the methods of prevention. If he/she inputs worker location or the construction process into this system, he/she can determine the relevant dangerous factors and suitable preventative measures. Also, it is possible to feedback changes in the work site. This information is sent to the server, which in turn, resends the feedback to the Monitoring system.

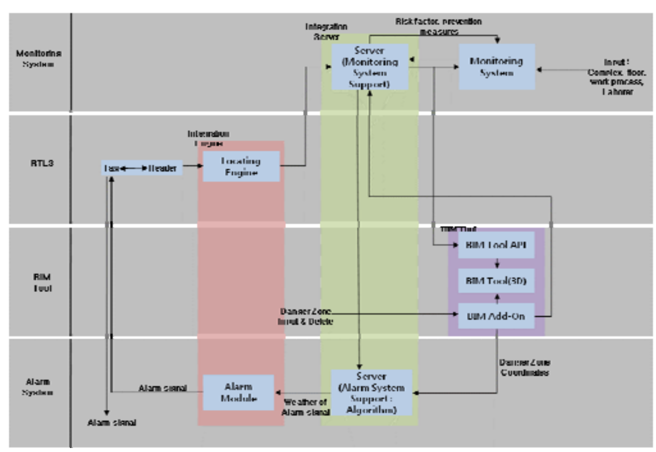


Figure 10. Data layout

4.2 Proposal for the realization of the program

To develop this program, the data layout between systems explained in Chapter 4.1 must be taken into account. The systems must be connected based on this data flow. The process of exchanging and connecting information between all the systems to create a whole system is seen in Fig. 11.

First, to connect the BIM Tool and the Monitoring System, the protocol between these two programs must be defined. As a result, the two programs will be able to exchange data freely. Next, the RTLS, the Alarm System's Engine, and the protocol between the Monitoring systems described above must be defined; then, all the programs can be integrated with each other.

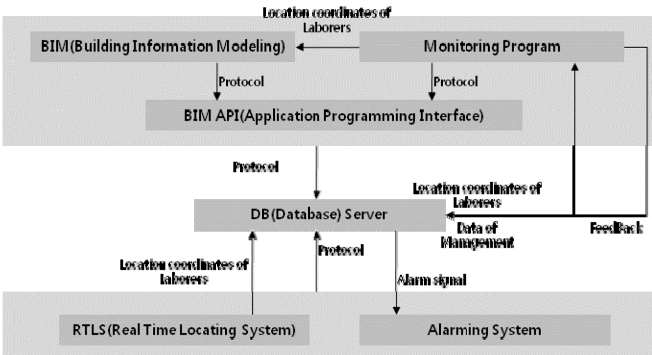


Figure 11. Proposal for the realization of the program

5. CONCLUSION

Currently, construction site safety management falls under the same standards, and it is not systematical but based on meeting the standard of tests. Therefore, ex-post treatment is more emphasized than prevention, which can result in considerable costs. Furthermore, safety management is often not as prioritized as other management activities (e.g., process, time, and cost management), and safety management may be extremely different from site to site, as it is highly dependant on the expertise of safety managers.

Therefore, this study proposed a program to improve current safety management practices. This program emphasizes prevention (e.g., workers are alerted with an alarm when they enter a danger zone) over ex-post treatment, and it is developed from the combination of a RTLS, BIM & real-time monitoring, an Alarm System, and a Data Mart.

However, to develop this program for practical use, further study is required. First, data modeling of the proposed monitoring program must be performed. When complex, building, floor, process, and workers are input, the dangerous situation and preventative measures should be derived according to these factors.

Furthermore, the current locating systems still have a few limitations. For example, the signals between tags and readers can be weakened in the presence of concrete and/or steel obstacles. This must be addressed so that the proposed locating technique is more suitable to construction sites.

Finally, after the system is developed, the program should be verified through experiments in actual construction sites.

ACKNOWLEDGEMENT

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S17-5

SUCCESS STORY OF THE SHIPBUILDING AND REPAIR INDUSTRY IN ACHIEVING EXCELLENT SAFETY PERFORMANCE: A LESSON FOR THE CONSTRUCTION INDUSTRY

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