

# Real-time Tracking for Intelligent Construction Site Platform in Finland and China: Implementation, Data Analysis and Use Cases

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## Abstract –

Production control, especially lean construction approaches, has necessitated the needs of eliminating waste onsite. Though the collaborative methods such as Location-Based Management System (LBMS) and Last Planner System (LPS) have proven the improvement of productivities, the process of data collection has still remained manual, which could result in inaccuracy and incompleteness. Automatically locating workers has been proposed to enable a method for production control in construction projects onsite. Thus, a platform is sought where an easy and passive tracking system is designed to enhance the production control processes.

In recent years, Finland is experiencing crucial transition from traditional production to digitalization formation while China has been a model where massive construction takes place as cities are expanding over the economic booming. The extensive building activities require a smooth and automated tracking system that can control and manage resources onsite to monitor in real time and examine the productivities more efficiently. This paper presents case studies in Finnish and Chinese construction sites where the proposed real-time tracking system was implemented, and the tracking data were analyzed for purposes of operations management. The model combines Bluetooth Low Energy (BLE) technology and 3G/4G network as connection methods, and explores the movements and time information of workers onsite, aiming to establish an intelligent construction site platform, which can be used for managing resource flow within lean principles in Finland and China.

## Keywords

real-time tracking, production control, construction, China, Finland, case studies

## 1 Introduction

Complexity and hazard in construction sites are not uncommon where coordinating and managing onsite resources such as labor, material and tools with high efficiency is usually challenging [1]. To overcome poor site management performance and improve the workflow in construction, production control has been introduced and developed over years from the perspective of lean construction including Last Planner System (LPS) [2], Location-Based Management System (LBMS) [3] and their integration [4]. The approaches have tested many applications and they are expected to contribute positively to plan and control production scenarios [5] where waste reduction and project duration elimination can be realized through production control and forecasting [6]. However, the data collected onsite depend on manual work of information input, which requires substantial amount of time and resources and could lead to errors and inaccuracy [7]. Thus, it is reasonable to believe that current stages of production control based on manual collection of data have not reached the full potential of site management [8].

In recent years huge amount of construction activities have witnessed the growth of the construction industry in China [9]. However, the risks of project delays, quality defects, low customer satisfaction, etc. have been a series of obstacles that Chinese construction firms have to face [10]. In China, the comprehension and application of lean approaches have still remained in early stages and studies of lean methods in construction are also rare [11]. On the other hand, Finland has been actively piloting lean methods in construction. For example, meetings and data collections were organized by Skanska Finland to execute LPS phase scheduling and define Locations Breakdown structure in addition to tasks and logic in 2010 [3]; I.S Mäkinen Oy as a Finnish turnkey contractor specialized in cruise ship cabin refurbishment

applied Takt Time planning in a project to shorten project duration and improve productivity [12]. Those applications have seen the enhancement of production control in construction, but the difficulties of manual data collection during the process are revealed at the same time [13]. Thus, China and Finland can be good candidates to test the real-time platform under different degrees of lean methods applied and to see if a standardized tracking platform could be developed to unify country-specific requirements (e.g. China and Finland) and enable the potentials of automation of real-time onsite monitoring in construction.

There are many mature tracking methods that have been tested in construction industry with a goal to promote transition from traditional management which is heavily rely on manual work towards more intelligent onsite monitoring system where automation plays an important role of utilizing the input information [14]: (1) Lin et al. suggested a tracking system to support analyzing laborers' behaviors using ZigBee technology[15]; (2) Costin et al. used radio frequency identification (RFID) technology for construction resource filed mobility and status monitoring in a high-rise renovation project [16]; (3) Cheng et al applied Ultra-wideband (UWB) for automated task-level activity analysis [17]. However, among those technologies, Bluetooth-based system are examined to offer high degree of simplicity thanks to its ease of installation [18]. Olivieri et al. (2017) proposed a prototype where Bluetooth Low Energy (BLE) technology was applied to track workers, materials and tools from the perspective of production control [19]. Furthermore, Zhao et al. (2017) implemented the system in a laboratory test and proposed the possible use case scenarios [20]. However, no tracking data have been analyzed for visualization of worker's daily movement or the visualization results from the tracking can be shown to back up the proposed use cases in practice.

Aiming to solve the gaps of lacking data visualization results from the proposed tracking system and visualization-based use cases, we implemented the model on both Finnish and Chinese cases using the standardized procedures; then we gathered, analyzed and visualized the data from a random selected worker to examine his/her daily movement in all cases; at last we proposed the potential use cases based on the visualization results suitable for both Finnish and Chinese scenarios. The paper is focused to answer the following research questions:

1. How to implement the proposed real-time tracking system following standardized procedures in Finland and China?
2. How is the data visualization of randomly selected tracking worker in the case studies based on the proposed system?

3. What are the use cases of this real-time tracking system according to the results of data analysis and visualization?

## 2 Methods

### 2.1 Description of the model

Olivieri et al. (2017) have explored the requirements and solutions of the real-time tracking model within the scope of production control using BLE technology [19]. This paper followed the same infrastructure of the system, tried to generate the data visualization and suggest the use case scenarios according to the results.

Figure 1 illustrates how this real-time tracking model works in reality. The model is featured with gateways, beacons and a cloud storage. Gateways are Raspberry pies that are fixed at different places in construction sites, and beacons are portable that can be carried or tagged to track workers, materials and tools. Beacons passively transmit Bluetooth signals to gateways and gateways can determine the relative locations onsite by calculating the signal strength received from the beacons (link 1, 2 and 3). The gateways are connected with WIFI or dongles that uses 3G or 4G mobile network to be able to connect to cloud storage. The cloud processes the incoming data, apply algorithms and logics in production control, visualizes the information, and displays the updates of time and location details of the tracking resources in real time (link 4 and 5). Thus, the data visualization results can serve the purpose of onsite management and monitoring.

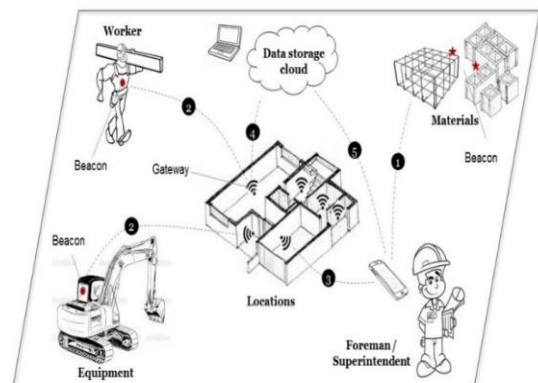


Figure 1. Proposed real time tracking scheme in construction site [19]

## 2.2 Implementation of the system in Finland and China

Case studies were scheduled one in Finland and one in China. For the Finnish case study, a residential renovation project was selected; for the Chinese case study, the onsite mechanical, electrical and plumbing (MEP) installation project was selected. We aimed to differentiate the project types and countries in our cases so we can test if the model can be applied in different forms and places with a standardized instruction and guidance. In our research, we aim to invest a platform as inexpensive as possible and still obtain holistic visualization information based on our light-weighted and easy implementation onsite. The cost for tracking gateways is 55 euro each and beacons for 4 euro each. Table 1 shows the case study description.

Table 1. Case studies description

Case	Companies participated	Tracked objects and beacon distribution	Number of gateways	Total cost of the system
Case 1. Renovation project in Finland	Renovation company	10 beacons to workers and 2 to foremen;	10 gateways onsite;	598 Euro
Case 2. Office building in China	MEP subcontractor	5 beacons to MEP workers;  1 beacons to onsite equipment	5 gateways onsite	299 Euro

### 2.2.1 Case 1. Residential renovation project in Finland.

The jobsite is located in Helsinki, Finland where we put 10 gateways and the warehouse for material delivery is located in Vantaa, Finland where we put 2 gateways. The renovation building is 3 floors where we put 1 gateway at entry in ground floor, 4 gateways in first floor covering each apartment, and 5 gateways in second floor with 1 additional one in the corridor. Figure 2 shows the simplified jobsite floor with gateways marked. The initial system setup time onsite is 6 hours with a few hours per week for maintenance. However, during the tracking period, the onsite conditions (e.g., gateway connections and locations) did not change, thus making the system maintenance work easy and convenient.

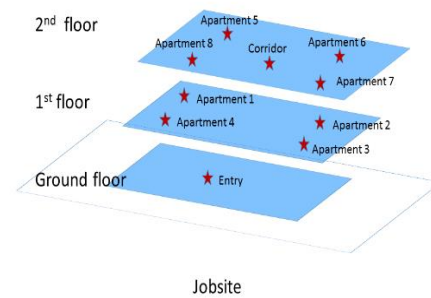


Figure 2. Real time tracking case study floor plan in case 1

### 2.2.2 Case 2. MEP installation project in China

We selected an entire floor in an office building of around 1500 square meters (open space with length of 50 meters times width 30 meters) to test the same tracking system. The jobsite is located in ShiJiaZhuang, a city that is about 100 kilometers from the capital Beijing. The tracking system monitored the work process of mechanical, electrical and plumbing jobs. Apart from case 1, 4 gateways were placed at each corner of the floor facing northeast, northwest, southeast and southwest. 1 gateway was placed in the middle closed to the entry of that floor. The setup time for the system onsite is 7 hours with approximate 2 hours per week to ensure the gateway connectivity stays valid. Figure 3 lists a floor plan of the jobsite with gateways installed.

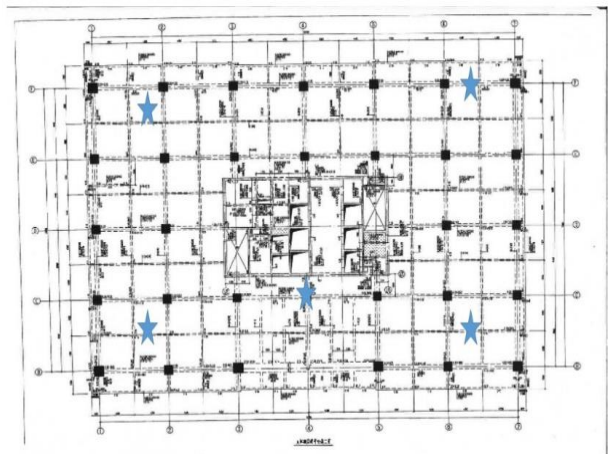


Figure 3. Real time tracking case study floor plan in case 2

### 2.2.3 Case selection and standardized instruction

We aimed to provide a standardized instruction for installation and implementation of the system onsite so

that we could overcome the country-specific requirement in practice and make the system function well regardless the construction site location. We selected Finland and China as a pilot places for testing because we wanted to see if the real-time tracking system serving the purpose of lean construction can be successfully implemented in these countries where one started to apply lean construction actively for many years [3][12] while the other still remained reluctant to explore the lean approaches [11]. Thus, it would be beneficial to see if the real-time tracking system under the scope of lean construction philosophy, because of its easy installation and automation data collection, can promote the process of applying lean methods in countries that are at the early stage.

We standardized the guidance of installation and instructions of workers in both case studies in order to

movement of workers, the details of random selected workers and time are listed in table 2.

Table 2. Random selected worker for tracking

Case	Random selected worker	Selected date
Case 1. Renovation project in Finland	Carpenter 2	June 5 <sup>th</sup>
Case 2. Office building in China	Plumber 4	January 22 <sup>nd</sup>

### 3 Results

timeline

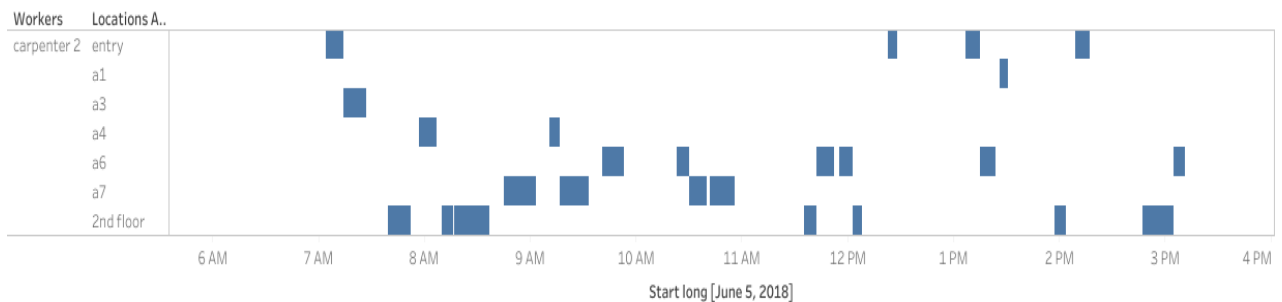


Figure 4. Movement visualization of tracking result for carpenter 2 on June 5th in Finnish case

promote the universal solution of onsite system implementation despite of the location or country selected. The general system implementation processes are: (1) determine the number of gateways and beacons needed; (2) configure file images into each gateway and activate beacons; (3) register beacons with predefined work type (e.g. plumber 1) in the tracking system; (4) onsite gateway installation and mark the gateway location precisely in the floor plan; (5) notify the workers of the tracking process and obtain their consents. (6) Tracking begins.

#### 2.2.4 Data analysis and visualization

The raw data in the cloud storage display thousands of recorded time intervals, which contains information including the tracking carrier (e.g. plumber 1), location, start time, end time and the time duration. Thus, the raw data is very fragmented and hard to comprehend. We filtered out large time intervals such as overnight durations, aggregated them based on site location and visualized the daily movement of tracking workers. The results are especially useful for proposed applications of use cases in different scenarios. To illustrate the

#### 3.1 Visualization result for the Finnish case

Figure 4 demonstrates the real movement line of the selected worker in Finnish case on June 5<sup>th</sup>. The horizontal axis indicates the timeline, and the vertical axis shows the location details of the time from 6am to 4pm. In the figure, a1 to a7 are the apartment numbers.

From the figure, we can see that the worker entered jobsite at 7:44 am and left jobsite at 3:05pm. The worker spent his/her first 10 minutes near the entry area and he/she actually first started at the work-related place (e.g. apartment a3) at 7:14am. He/she probably had a lunch break between 11am and 11:30am, and possibly had several coffee breaks between 9:50am to 10:20am and between 12:40 pm and 1:05 pm outside of the jobsite. Since the worker stayed at the second floor the most time during the tracking period, it is reasonable to think that he/she did the most work in the area (especially apartment a6 and a7).

### 3.2 Visualization result for the Chinese case

We executed the visualization process following the same method and obtained the results for the random selected worker daily movement in Chinese case as in Figure 5.

The horizontal axis indicates the timeline details from 6am to 12pm. The worker did not spent time in northeast area so the system automatically filtered out that location in the figure.

#### Sheet 2

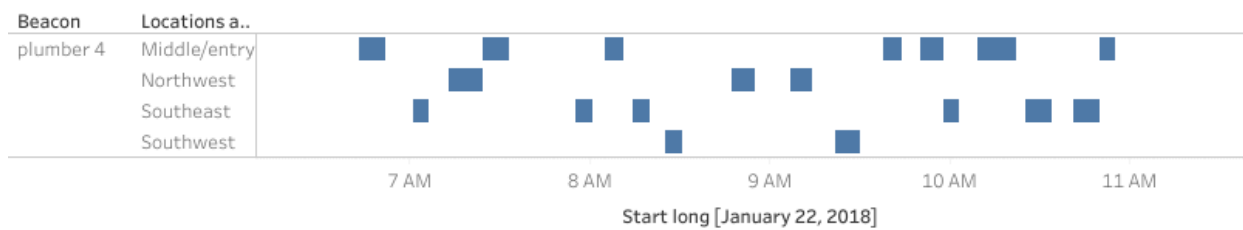


Figure 5. Movement visualization of tracking result for plumber 4 on January 22<sup>nd</sup> in Chinese case

We can see the plumber entered the jobsite at 6:43am and left the tracking floor at 10:56am. The visualization figure indicates the scattered movement for the worker onsite while in schedules they are typically expected to finish a task in one location before moving to another. This corresponds to our assumption of existence of potential construction waste in jobsite.

### 3.3 Use case proposal based on visualization

Zhao et al (2018) has suggested several use cases based on real-time tracking system for monitoring the movement of workers in construction sites [21]. However, the paper has not connected the proposed use cases with the actual data visualization results so that no real-life results have yet backed up those use cases. Because of this, we explored the use cases based on the data visualization to promote the underlying tracking system into more practical level.

#### 3.3.1 Waste detection and value-adding activities

Based on the visualization figures, the movement line of a worker can be displayed. It is clear to see how much time the worker has spent in different locations including entry area and offsite. For both cases in Finland and China, workers have spent quite much time in entry area, which would be a notable factor to result in waste on the jobsite. Though it is difficult to judge accurately if a worker has wasted time in the work areas, the waste level in terms of time spent on entry and offsite is obvious and worth noticing for site managers.

Waste level is tied with value-adding activities, which is an important use case for lean construction applications. In figure 4 and 5, the tracking visualization

has indicated that the second floor areas in Finnish case and the southeast area in Chinese case are the main workplaces that the laborers performed their jobs. Thus, by aggregating the time durations that workers spent on workplaces to compare with total time of the day spent onsite would be a good use application to explore the value-adding level of the workers.

#### 3.3.2 Safety control

The visualization helps with jobsite safety control in an efficient way. Since the visualization results are classified by location in vertical axis and time in horizontal axis, it is easy to apply safety control in the specified jobsite areas. For example, if southeast area in the Chinese case was alerted as an access-restricted place, it is straightforward for site managers to check whether or not and how many times the workers have entered the area and how much time they spent there. Since the beacons associated with carriers send signals passively to gateways, notifications can be sent to management and worker themselves in real time.

## 4 Discussion

### 4.1 Location-based tracking data visualization improvement

Figure 4 and 5 visualized the selected workers' movements in one day based on location and time information from the system. In vertical axis the locations were listed without real-life connections with each other. For instance, in Finnish case, the carpenter first entered the entry then moved to apartment a3 and the movement line connected both ends in the figure. However, it cannot give the information that the workers have necessarily passed through apartment in between. For better visualization experience in future research, 3D approaches are recommended to enable the logics and pathways between tracking locations. BIM applied in construction would be a good candidate to be integrated in the real-time tracking system.

## 4.2 Value-adding activity determination

Time spent on entry area or outside of jobsite during worktime can be determined as waste or non-value-adding time. However, it is of difficulties to define the amount of value-adding time even if the workers are detected in the workplaces during the worktime. In further studies, the data visualization process can be linked with workers' updated schedule for better recognition of value-adding activities onsite. If a worker is scheduled in a place for his/her work, the time spent in that workplace and captured by the real-time tracking system is more likely to be value-adding activities onsite.

## 4.3 System limitation and country-specific requirement

To make the tracking system function, gateways need to be connected with internet and power throughout the period. This could be challenging for construction jobsites equipping with all necessary supporting devices. Besides the system limitation, country-specific requirement is also important to observe. For instance, in Finland, it is by law required to get workers' explicit consents of tracking and labor union needs to give a pass too. In China, onsite device safety protection is needed from stealing when the tracking gateways are exposed in the open space. Internet connecting stability is another matter to ensure the usability of the system in China

## 4.4 Comparison discussion for future studies

The BLE real-time tracking scheme has been successfully implemented in both Finnish and Chinese construction environment and the data results were good for visualization. Compared with the Chinese case, the gateway placement in Finland is denser and in apartment-specific level in contrast of floor level. This provides an interesting perspective when it comes to the optimal gateway tracking placement strategy corresponded to different requirement of detail level of tracking. Furthermore, the visualization analysis can be executed in future study where the workflow and logistic flows can be researched as combination by tracking multiply onsite resources, therefore meaningful metrics such as utilization rate, uninterrupted presence of workers at work location, and material moving times in the building can be calculated and compared in Finland and China for its productivity and waste level of construction projects.

## 5 Conclusion

The paper has provided a set of standardized guidance and instructions on onsite implementation of BLE technology based real time tracking system. The model follows the principle of production control in construction under the scope of lean approaches, aiming to improve the productivity and decrease the waste onsite.

The case studies were scheduled for actual construction projects in Finland and China, providing time and location information that is recorded in real-time automatically in the system for data analysis. Furthermore, the paper presented the data results by visualizing the movement path of randomly selected workers in both cases. The visualization backs up the two proposed use cases in practice where waste detection can contribute to identifying the value-adding activities onsite and safety control uses can prevent men from entering the restricted areas. The contribution of the research is developing a light-weighted and low-cost tracking system, suitable for multiply construction projects, to seamlessly obtain movement and time information and provide managerial implication to workers and site managers. In future research and the further development of the system, the model is expected to enhance resource flows in construction and automate the management process in a smart and effortless way.

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