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# Data Analysis on Applying Real Time Tracking in Production Control of Construction

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*Abstract* – The interest in production control has increased over recent years, especially among lean construction practitioners. Despite of advanced planning and control methods, the data of on-site processes are still typically collected manually. At the same time, technology has been developed to the point where it is possible to remotely locate people, equipment and products in supply chains. Therefore, how to obtain and manage data in construction based on real time tracking is critical to change production control to a more real-time and less laborious process. The availability of real-time, location-based data, opens possibilities to revolutionize production control.

This paper proposes a prototype of an intelligent system for real time production control on construction site, defining the types of the tracking data, and investigating the utility of them. The prototype combines Bluetooth and WIFI network as connection methods, and locates resources and their movements in real-time, which can be used as a reference to explore proper solution on construction projects and potentially improve production efficiency, sustainability and management of workers.

*Keywords* - production control, real time tracking, system set-up, laboratory test, construction, data analysis

## I. INTRODUCTION

Production control in construction has been discussed under lean construction philosophy, including methods such as Last Planner System [1], Location-Based Management System [2], and their combinations have already been tested and applied in many cases [14]. The methods are becoming more commonly used to plan and control production in construction projects. Their main uses have been to enhance resource efficiency through waste reduction [1] and to decrease project durations through advanced production control and forecasting [15].

Smooth coordination of construction activities and specialized information systems are required to overcome the complexity of interactions among labor, materials, space, equipment and products [5]. Mobile applications through the Internet of Things (IoT), as recently developed tools, can assign the plan to the construction workers and allow them to use the mobile devices to report the progress [3]; however, the approaches usually rely on manual input of process information requiring human work to collect and analyze the data and leading to potential human errors [2]. Thus, the current manual approaches are not realizing the full potential of production control [17]. It is proposed that one way to fulfil the gap of construction lacking real-time monitoring on site is to develop a system to provide

prompts analysis support of laborers' behavior [9], material usage and equipment movement in one platform.

In recent years, real time tracking has been proposed in different industry applications, where newly developed wireless technology is integrated to capture reliable data to serve operational management in indoor production and navigation [4]. Different solutions of wireless technology for real time tracking were compared and discussed in earlier studies (e.g. [13]). Among representative proximity sensing technologies such as RFID (Radio-frequency identification), Magnetic Field and ZigBee [9], Bluetooth technology proved to be the most promising method because of its highest level of simplicity with minimized infrastructure, ease of calibration and ease of installation [13]. Real-time location (RTL) system was developed for multiple movements of workers in confined construction sites [8]. Furthermore, Bluetooth low energy (BLE) mobile tracking sensors have been applied on construction-safety monitoring framework [12] through seamless safety monitoring integrated with Building Information Model (BIM). BLE technology applied on RTL indicates that it could improve the system stability and efficiency onsite. However, the system and those tracking approaches have not yet been targeted on production control to enhance productivity or detect construction waste.

Aiming to fulfil the gaps in real-time production control in construction, this paper proposes a prototype of an intelligent system, to fulfil relevant requirements of real time production control: (1) productivity enhancement and waste reduction; (2) location-based information on a pull basis; (3) material logistics control and; (4) safety management. The paper first illustrates a laboratory prototype of a real-time tracking system. Laboratory tests are used to identify potential and limitations of the proposed prototype, aiming to answer the following research questions:

1. What types of data can be obtained for real time tracking?
2. How accurate the data is to define location of an object?
3. What is the potential use of real time tracking data in production control?

The data results were extracted from the test where movement tracking information was obtained in real time and on daily basis. After that, the potential of the prototype was identified, the utility of tracking data was discovered and the hypotheses of further analysis in terms of

production control were proposed. The paper would connect the tracking data based on laboratory test to further research on the solution to enhance the construction productivity and sustainability, and lower the waste in real practice.

## II. METHODOLOGY

### A. Description of the prototype

The proposed prototype for real time tracking and production control contains four main components (Figure 1): beacons, gateways, a cloud storage and a web-based application. The workers and equipment are equipped by beacons which are constantly sending signal data to gateways with BLE technology (link 2). Gateways receive different strength levels and report them to cloud service via WIFI network (link 4). The cloud utilizes an algorithm to transfer those signal strength levels into relative location information based on the strongest signal strength. Then the cloud stores the incoming worker and equipment movement information, analyzes the tracking data and displays the results on web-based application through application programming interface (API) where the tracking requirements are defined (link 5). The web-based application is used to update location information and production status based on suggestions from cloud (link 3 and 5). The prototype also provides the possibility to include material tracking into the system (link 1).

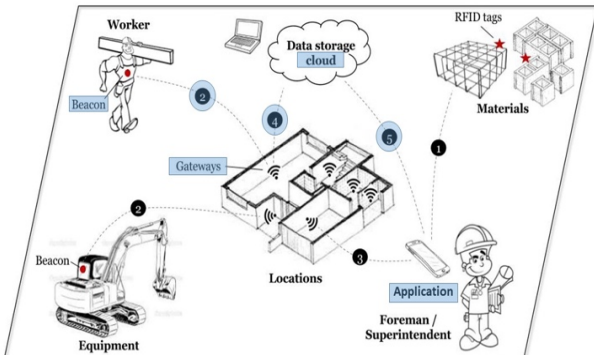


Figure 1 proposed real time tracking model for production control in construction (adopted from [11])

### B. System set-up for prototype laboratory test

The purpose of the laboratory test is to analyze the feasibility of the proposed system. The analysis focuses on identifying what kind of data can be obtained through the prototype and how accurate is the obtained data about workers' locations. Thus, the test will mainly focus on links 2, 4 and 5 in Figure 1. Based on the test, we summarize what types of tracking data are useful for the purpose of productivity enhancement and waste reduction.

The laboratory test was set in two corridors (floor 2 and floor 3) of Department of Civil Engineering, Aalto University, Finland, where six gateways in total were placed along the corridors. Five beacons were tracked representing five different university researchers. Gateways 002 and 005 are placed in the office rooms, gateways 003, 004 and 008 are placed in the coffee rooms,

and gateway 010 is placed in the corridor. The location strategy aimed to detect movement of workers in both working and off-working areas. In order to test data accuracy, gateways were placed closer to each other on purpose so the possible obstruction of signal transmission can be identified. Workers were instructed to move as usual during one day (tracking window: 8 am to 6 pm). All gateways were detecting movements of beacons where the one with strongest signals determines the location of that specific worker within the circle area. A web-based application was developed to request data responses from API based on the cloud in real time where the time stamp information of beacons can be recorded for analysis. The confidence circle from a sub-test is introduced to indicate how accurate the signal can be in the model. The circle covers the area with the probability that the respective gateway can correctly detect the location of beacons. The strategy of calculating the signal accuracy confidence level is based on the accumulated sum of seconds within 1 minute that did not show the right location (gateway) when one is at the edge of the respective circle. The edge of the circle is determined by several chosen points near the gateway such as doors or windows when the test person stands still at these points (Figure 2). To avoid bias, 2 beacons were carried at the same time and the seconds were calculated on their average value in the same circle.

### C. Defining tracking data and their potential use in production control.

An analysis of tracking data is essential to define the right types of real-time information needed for production control in construction, and necessary to transition the laboratory test to real application on site.

The types of data and use potential of the framework were defined based on the developed API returned responses, observations onsite in laboratory test and literature reviews.

## III. RESULTS

### A. Obtained tracking data

Based on the laboratory test, four type of tracking data can be collected (Table 1 and 2): 1) time spent in each location (horizontal attributes), 2) worker's time divided to locations (vertical attributes), 3) real time location of workers (red color), and 4) time stamp of workers.

Workers	Gateways and Locations						Total in range time
	Gateway 003	Gateway 004	Gateway 005	Gateway 008	Gateway 010	Not in Range	
Data report on May 12, 2017 in minutes							
A	50	84	356	8	2	54	500
B	0	182	289	4	0	167	475
C	0	205	212	10	4	25	431
D	9	62	284	1	6	141	362
E	0	115	10	3	5	256	133
In Total	59	648	1151	26	17	643	1901

Table 1 Integrated tracking data report and location in real time

Note: Red background indicates the current location of the worker  
Real time tracking last refreshed: 2017-05-15 14:13

The time stamp is more concrete information that is thoroughly recorded in the system to integrate the timeline and movement for one specific worker. This contributes to production control by enabling foremen or superintendent to check the time slots of workers in real time or on daily basis, especially the start and finish time of the worker. Table 2 shows the time stamp information for worker 2 on May 12, 2017. Highlighted table cells indicate that worker 2 started the job at 08:00:41 and finished at 18:43:26. The time slots are sorted by timeline from morning to night.

Worker	Gateway	Start	Finish	Gateway	Start	Finish
2	005	08.00.41	08.02.03	004	08.02.03	08.02.24
	005	08.02.25	08.59.31	008	08.59.32	09.01.23
	Not in Range	09.01.24	11.48.16	005	11.48.17	13.03.02
	004	13.03.03	14.59.52	005	14.59.53	15.03.39
	008	15.03.40	15.05.31	005	15.05.32	15.09.44
	004	15.09.45	16.09.31	005	16.09.32	18.37.40
	004	18.37.41	18.43.26			

Table 2 Time stamp for worker 2 on May 12 in 24-hour format

### B. Signal accuracy analysis

Figure 2 shows the detailed gateway placement information with confidence signal coverage in circle which was introduced in methodology section. Beacons can be detected near the respectful gateway with confidence level within each circle. Confidence % means the percentage of the time the beacon is accurately detected as belonging to that location. For example, within the inner coverage circle of gateway 005, the signal accuracy is 87%, which indicates beacons in that circle can be detected correctly during 87% of the test time. Overlapping areas of nearby gateways results in uncertainty of beacon location in that area. Table 3 shows the signal accuracy of each gateway in terms of confidence level. For instance, at the edge of outer circle of gateway 010 coverage, the experiment shows that within 1 minute, for around 26 seconds the system did not show the beacon was at gateway 010 (Confidence = 26/60 seconds  $\approx$  57%). Within the inner circles, the average confidence level was 85 % and within the outer circles 57 %.

Gateway No.	Incorrect seconds accumulated within 1 minute Inner/Outer circle (1)	Correct seconds accumulated within 1 minute Inner/Outer circle (2) =60-(1)	Signal accuracy confidence Inner/Outer circle (3) = (2)/60%
002	10/14	50/46	83%/77%
003	9/29	51/31	85%/52%
004	17/24	43/36	71%/60%
005	8/10	52/50	87%/83%
008	0/12	60/48	100%/80%
010	9/26	51/34	85%/57%

Table 3 Signal accuracy confidence level in details

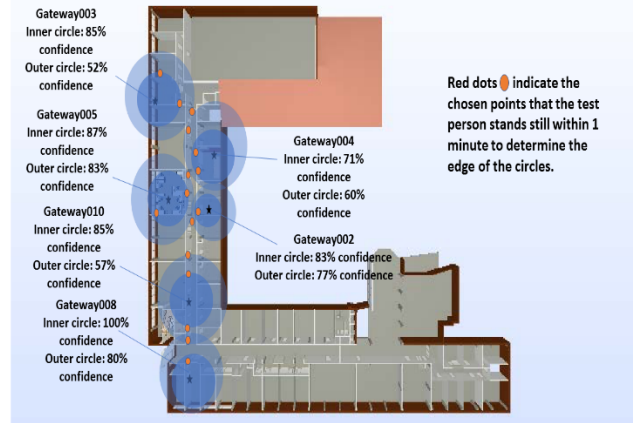


Figure 2 Gateway location on floor 2

### C. Use of real time tracking data in production control

The data can contribute to production control by providing the proportion of time that each worker stayed at each location, therefore waste and productivity can be determined by comparing and analyzing the records, for instance, the time distribution between work areas and off-work areas or the time workers spent outside of the location they were supposed to work in. Based on the laboratory tests and requirements of production control in construction, two different ways to use real time tracking data of workers were identified.

#### 1. Time analysis:

From time information matrix (Table 1), it is possible to calculate the time spent in each location (gateway) by each worker (beacon). Thus, from this analysis, the goal of the following can be fulfilled:

- 1) *Worker's daily movement analysis to reveal work interruptions and non-value adding moves.* Movement line can be drawn accordingly with time spent proportion. Figure 3 is an example for worker 4:

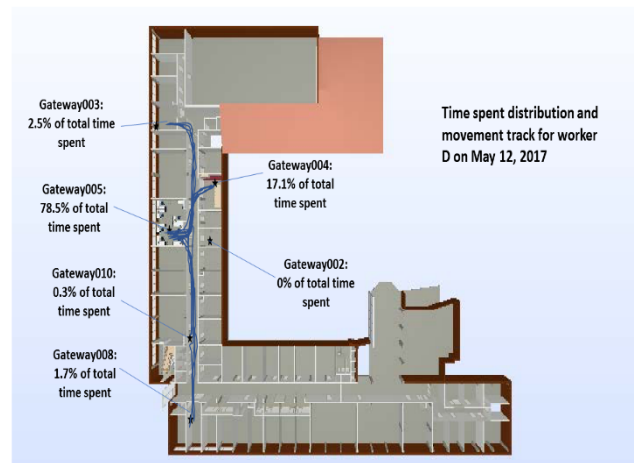


Figure 3 Movement line and time spent distribution of worker 4 on May 12 in BIM based on time info analysis

- 2) *Worker's time division per day to identify value-adding time.* The data provides value to identify the productivity of workers by comparing their time spent distribution on each location to the planned location where they were supposed to work.

- 3) *Vacant time per location to identify work-in-progress.* Vacant time can be determined by looking at the time spent on off-work area and not-in-range time.
  - 4) *Information of time spent per location available to measure work productivity.* The total time that has been spent on each location can be determined. For instance, from the results it can be clearly seen that workers have spent 1151 minutes in total at the area of gateway 005.
  - 5) *Several workers in same location to identify possible congestions.* The data provides value to examine the work progress and congestion by comparing worker's tracking data from one another.
  - 6) *Real time location of workers to catch up them in any given time.* The status of the workers can be tracked and displayed in real time.
2. Labor waste analysis in production.
    - 1) *Individual labor waste.* In laboratory test, the tracking of beacons carried by workers can tell how much time they spent in the location where they are planning to work. Waste can be identified by any detected movement outside of the planned area or workers moving to unplanned areas. Some "edge gateways" can be placed at the boundary of the planned area for work, to receive the entry/exit signal to control labor waste.
    - 2) *Workers looking for other workers.* It is possible to detect the waste of looking for other workers (or superintendent) by looking at the patterns of movement. For example, it is possible to find out if a lot of workers waste a significant amount of their time looking for foremen or the superintendent.
  3. Possible extension to material and equipment tracking
 

Since beacons can be tagged also on materials and equipment besides workers, it can be extended to the integration of tracking labor, materials and equipment where the construction work can be validated based on the how the three factors are related to each other.

    - 1) *Material waste* can be evaluated by figuring out how many times the material is moved before it ends up in the work zone where it is supposed to be consumed.
    - 2) *Workers looking for materials.* It is possible to evaluate the waste of workers looking for materials by analyzing the movement of worker before he/she starts moving together with the material (= hauling material).
    - 3) *The equipment work process* can be also monitored by checking if workers and tools are moving together in the same place.
    - 4) *Equipment moving materials.* The system may verify if this works properly by trying to check if materials, the equipment and its operator are moving together in the same place.

## IV. DISCUSSION

### A. Tracking data accuracy

Data accuracy is a critical factor that influences the feasibility of the proposed prototype. The signal accuracy indicated by confidence level was not satisfactory. Reasons can be foreseen that the system lacks a formula that could identify the immediate location change and respond to that without delay. In the tests, the location information changes back and forth within a short period of time. This implies the need to improve the cloud brain to get closer to a 100% accuracy. To enhance the data accuracy, some suggestions are proposed:

1. *Developing positioning algorithm in cloud brain.* Reference [9] suggested a localization algorithm which is a fingerprinting technique based on specific behavior of radio signals. The solution helps achieve accurate relative positioning and target mapping [10].
2. *Averaging the signal over longer time periods.* Sudden change of location may lead to dramatic signal strength fluctuation. Thus, averaging the signal during longer periods could potentially stabilize signal change, making it a smoother location switching process.
3. *Adjusting transmission power and broadcasting interval of beacons according to distance among gateways.* High volume of transmission power and broadcasting interval of beacons can add complexity and error when gateways are placed close to each other. Adjusting the power can contribute to signal strength flexibility and connectivity.

### B. System Improvement

1. *Optimize location of gateways.* Accurate placement of gateways can strengthen stability of the system since gateways play important roles of communicating with cloud service and receiving tracking data from beacons at the same time. The placement of gateways can be optimized by exploring the boundary and coverage of beacons. For instance, the majority of worker's movement in one day is recommended to fall in the range of signal coverage circle with high detecting confidence level (e.g. above 90%); overlapping area of circles with high confidence level should be adjusted to the minimum.
2. *BIM integration.* BIM can potentially enhance various aspects of construction and operations management, especially when integrated with complementary approaches of data visualization, analytics (Big Data), sensing and communication (communication technologies, internet of things) [6]. It is widely used in the design phase for virtual design and construction [16]. The proposed prototype is prepared for the next step to integrate with BIM in the future. With the help of the API that is designed for the prototype, a platform can be created where it is possible to locate the movement in BIM in real time. The information can be used to provide safety guidance with good visualization for foremen to monitor and give permissions to workers to enter the hazard locations.

### C. Hypotheses to improve sustainability of construction

Real time tracking can improve sustainability of construction both from environmental, social, and economic aspects.

#### 1. Waste reduction (*environmental and economic aspect*)

Waste detected in real time can enable foremen or the superintendent onsite to act much quicker than traditional ways. Instead of waiting for report of waste analysis, dynamic waste information becomes available every day by automatically analyzing the tracking data in the cloud which helps respond to changes and decision-making. Thus, production efficiency in construction is expected to enhance significantly.

#### 2. Safety guidance (*social aspect*)

Researches have evaluated the performance of the automated safety monitoring system in Atlanta, Georgia [12], which validates the application of BLE-based location tracking. To develop Park's solution, safety monitoring system can be put in BIM to enhance visualization effects, where gateways can act as part of alarm system where workers would be instructed whether they entered a dangerous area in real time tracking. Foremen on site can also use the system to approve only necessary workers to enter the dangerous area.

#### 3. Cost analysis (*economic aspect*)

According to time stamp matrix that has already been defined in the prototype, hypotheses can be made that the total time that one worker has spent on site should be connected to the salary system that determines his or her work hours every day. Compared to the keycard system that is being used in most work cases nowadays, the start and finish time of workers can be automatically recorded and stored in the system.

## V. CONCLUSION

The laboratory test provided valuable information of how workers can be tracked, what types of tracking data can be obtained and analyzed, and what is the potential use of real time tracking framework.

Movements of workers and location-based time information were captured and analyzed through the laboratory test. The paper proposes a new methodology of determining the accuracy level of the model, and potentials of the prototype for real time tracking in terms of time analysis, labor waste and extension to material and equipment tracking. Furthermore, the paper discusses the suggestions of improving tracking accuracy and the system, connecting cost analysis and safety guidance to enhance production control from different perspective in construction. With efforts to continuously improve the model, the feasibility of the application is expected to be validated for larger construction projects in future.

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