RTLS systems as a Lean Management tool for productivity improvement

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Abstract – There exists many types of different RTLS systems that can be used in the construction sector for tracking people and assets. Previous research showed that such system can be used with success especially during the construction stage of the object. Lean Management is a methodology based on waste reduction in production processes focused on productivity improvement. This methodology is widely used in different sectors, including construction, where it can be effective and results can be visible for all interested involved parties. A goal of this paper is to present RTLS systems used for tracking construction process and with the focus on Bluetooth technology for object tracking. Authors presents the idea of using locating systems for efficiency improvement as a part of Lean Management strategies implementation on the construction site. Discussion is made in the field of construction process showing where they can be used and at what stage in introduction LM strategies RTLS system is most useful. Authors illustrate this idea with the results of the research performed with Bluetooth RTLS system used for tracking objects in the building planned for renovation.

Keywords –

Indoor positioning systems; Sensor technologies; Automated data acquisition; RTLS; Lean Management; Beacons; Bluetooth; Lean Construction

1 Introduction

In recent years, many advanced wireless tracking technology solutions have been developed by scientists and companies interested in implementation of those solutions into constructions sector. Numerous research studies have developed approaches for applying Real Time Locating Systems technologies to construction projects and facility/infrastructure management, and in particular, construction site assets tracking [1]. The development and extensive use of technologies: Radio Frequency Identification (RFID), Ultra-Wideband (UWB) and Bluetooth Low Energy (BLE) has improved location tracking for allocating labor, materials and equipment resources as well as improved health and safety [2 ,3 , 4] in many sectors of industry.

New technologies are important help for the Lean Management methodologies, since having possibility of storing real data from construction site it is easier to analyze it and later use it for process improvement that results in time, money, and resources savings in the processes. So far many times it was not possible for introduction of improvements, because it was difficult to track and save data to realize where the problems lies, and which kind of actions can be taken to resolve them. RTLS systems can serve as a tools that can effectively find the waste associated primarily with the movement of workers and resources

Authors in this study decided to present the possibility of using Bluetooth based RTLS system for assets tracking checking its accuracy and performing root cause analysis for the results that was obtained, to check why results are not as precise as expected, and how were they influenced during the research.

2 RTLS systems

There is no universal definition of RTLS system, but the main idea is to combine the appropriate hardware and software to automatically determine the coordinates of the tracked object in real time, within a given area. Data collected by RTLS can be used not only for control at the given moment, but also for further analysis, what, if there is a need to eliminate unwanted actions and behavior, can be very helpful [5].

There are many types of systems RTLS consisting of different types of location sensors and operating using many location technologies available on the market. The idea of the system lies in communication with the tag by the signal receivers, and its location is calculated using a variety of software algorithms to analyze the received data. Depending on the type of technology, the accuracy of the tracking system varies. Table 1 shows the most popular localization technologies used in construction, along with information on their accuracy.

Table 1. Accuracy of location technologies used in construction sector [5]

Localization Technology:	Accuracy:
RFID	0,86-2,6 m
Satellite (GPS)	2,15-4,36 m
UWB	0,3 m
Vision analysis	0,658 m
WLAN	1,5-4,57 m
Ultrasounds	0,04 m
Infrared	--

As shown in Table 1, the best accuracy is achieved using a system based on ultrasound signals and UWB. The least accurate system is the satellite GPS system. It should be noted that in December 2016 a satellite system GALILEO was launched [6], which accuracy can be closed to UWB levels, but there is a need to wait for attempts to use this type of system in the construction industry.

Attempting on location of the object during the process of construction is also associated with certain limitations in terms of the technologies used. Some of them (GPS) will not work indoors - as necessary in this case is the visibility of the satellite, others (UWB, WLAN) will require the installation of special additional network and receiving equipment on the construction site. There is currently no universal solution that would be good for all applications in the construction industry, which is why the selection of the system should be carried out carefully taking into account the objectives and purpose of its implementation and also the type of tracked objects (tools, material or people).

2.1 Bluetooth in construction

The idea of use of Bluetooth technology as RTLS for the construction industry purposes is not widely available in the literature. In the Thomson Reuters Web of Science Core Collection database, which comprises of seven different citation databases including different information collected from journals, conferences, reports, books and book series [7], there are only 4 articles related to RTLS and Bluetooth keywords. One of them is associated with checking the accuracy of the system for the health care purposes [8]. The results showed that for the given boundary conditions, the locations become unreliable as they change too much and only under specific requirements. Authors indicated the need for more precise studies in this field. Other research was performed in the same area and it was a pilot study prepared to serve as a guide for developers of applications (for software as part of localization) and as help to identify potential research problems and future products [9]. Bluetooth location systems were also studied in terms of big data process environment [10] and was taken as a reference point for comparison with ZigBee solutions, which are similar to Bluetooth technology [11].

Majority of authors of analyzed works indicated that the use of positioning technologies such as Bluetooth, infrared, audible sound, and magnetic signals have yet to be studied (or reported) in the construction industry [5] and the location tracking system needs to be improved further to make them more reliable [8], which is why results presented in this article fill the existing knowledge gap on accuracy research of this technology.

3 Lean Management

Lean Management is an idea identified with the management, which has its foundations in MIT. It was first used by Johnny Krafcik in publication that discusses the results of an international research project on the automotive industry, related with the look for the reasons for predominance of the Japanese producers delivering cars using traditional management techniques over different countries [12, 13].

Lean thinking can be summarized in five fundamental goals [14]:

- eliminate waste,
- establish value stream,
- encourage flow,
- pull production,
- pursue perfection.

The reduction of waste in places where it is possible, and orientation to creation of added value for the end customer [15] is one of the most important, which is implemented through a variety of methods introduced at the stage of planning and production of the product.

The implementation of lean production in construction is known as Lean Construction [16]. Wasteful practices can be described as those which increase time and cost and reduce reliability without adding value to the final outcomes of the processes [17]. In the literature [18, 19] 8 main types of waste are indicated which with help of the Lean Management tools can be successfully eliminated:

- overproduction,
- waiting,
- over-processing,
- transportation,

- storage,
- unnecessary movement,
- defects,
- non-utilized talents.

All of these waste can be observed also during analysis of the construction processes, so Lean approach is nowadays more and more widely used in construction [20]. At the same time more often those methodologies are applied to improve the implementation of other measures in areas such as health and safety [21] and BIM [22], using the assessment of, among others, elements of fuzzy logic known from decision-making in the production management [23].

4 Case study

For the purpose of the article authors decided to perform research connected with checking the possibility of locating objects in existing building. The idea was to use the Bluetooth system for improving renovation processes by enabling direct location of the objects like equipment or materials.

Figure 1. Faculty of Civil and Environmental Engineering Building – front view [photo by Poznan University of Technology]

4.1 System description

Authors performed test on the devices received from one of the European Beacon producers. Beacons are based on Bluetooth Low Energy (BLE) which is a medium ranged transmission standard aiming for cheaper devices with longer lasting batteries [24]. Tested Beacons were designed initially for advertisement industry.

During the research there were totally 15 devices used. Each Beacon has dimensions about 60 mm in diameter and about 15 mm thickness. Devices were equipped with the CR2032 battery and had range, according to the producer, of 70 m. Devices were design to work inside of the building. Producer together with the equipment provides online CMS platform, where it is possible to:

- Manage the Beacons (also of other manufacturers) - adding devices and assigning them to different campaigns, locating navigation units in a construction plan integrated with Open Street Maps and defining area labels.
- Monitor and modify navigation parameters such as frequency, signal strength, battery status.
- Read data and traffic statistics or the number of people present in the area of interest and their visual analysis.

Except from described platform there was also mobile application available which is required for communication between CMS system and Beacons. It is responsible for updates sent to the content management system. The update occurs when the device (mobile phone) with the application enabled is within range of the Beacon.

There was also another mobile application which was specially design to search and locate for individual items that, upon discovery, appear on the on-line building plan in CMS. The application acts as a scanner - it is necessary to appear within the Beacon range in order to read the location of individual asset. These data are then sent to the web platform, which displays the location. Tested application was in beta version, since the producer was still working on improving the localization system at the moment of performing the research.

4.2 Research procedure

Research was performed on the left wing of 3rd floor of Faculty if Civil and Environmental Engineering building located in Poznan, Poland. Building is planned for renovation within 24 months. The three-store building with basement was made of demolition brick, with DMS prefabricated ceilings with reinforced concrete was constructed between 1953-55y on the old military baronets of fort Rauch in Poznan (Figure 1).

Authors prepared digital plan on the basis of a manual inventory drawing of the object. Then it was entered into the platform integrated with Open Street Maps, as shown in the Figure 2.

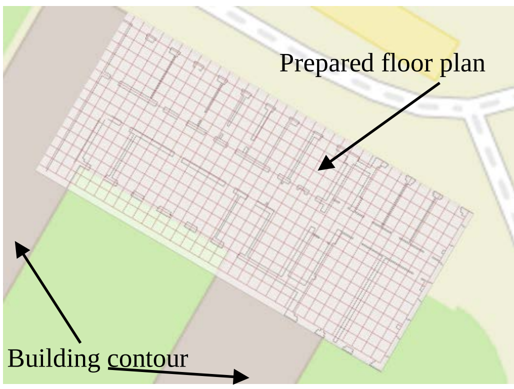

Figure 2. Floor plan in the on-line tracking system integrated with Open Street Maps

The Beacon producer makes it possible to change the frequency, wavelength and signal strength of each Beacon on the internet platform. Sensors were programmed to -23dB for the whole test procedure, which was the smallest possible value that the system can provide. Signal strength has been selected based on manufacturer's recommendations.

It has to be noted that in the online system user has to assign role for each Beacon. Some of the Beacons acts like a grid for location objects, others acts as searched assets.

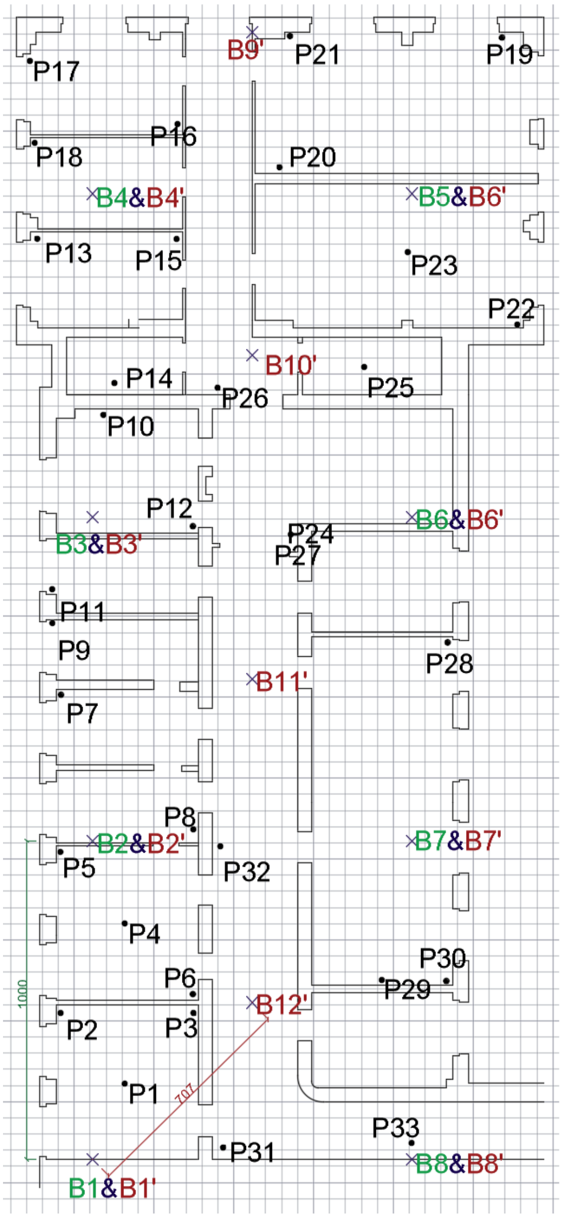

Figure 3. Grid scheme (green- 1st with 10,0m spacing; red 2nd with 7,07m) with location of 33 measuring locations (P1-P33)

In the next step, the Beacon grid was depicted as shown in Figure 3 and the first series of measurements was made. Next, the grid was consolidated by adding three additional sensors, which reduced the distance between grid points.

The distance was (A) – 10 m and (B) – 7.07 m, respectively. Each Beacon was placed at the same height - 1m, and at appropriate distances from the walls, according to the drawings. There were in total 66 measurements in two series for 33 each. Tracked objects were placed at different distances from the mesh sensors as shown in Figure 3, where positions were marked as (P). During conducting measurements in the second grid, the layout of the searched objects was reconstructed and the impact on the mesh density was investigated. By changing the placement of asset's Beacons, a mobile device was approached to communicate with the system which was necessary to save the searched location sensors into online system.

The final test results were calculated using screenshots from mobile phone (Android system), on-line CMS accessed via desktop computer and the actual location of the sensors.

After receiving results there was also performed root-cause-analysis to find out what caused such results and to assess the possibilities of use tested equipment in construction sector.

Performed procedures and action are illustrated in the Figure 4 for better understanding of what steps have been taken by the researchers.

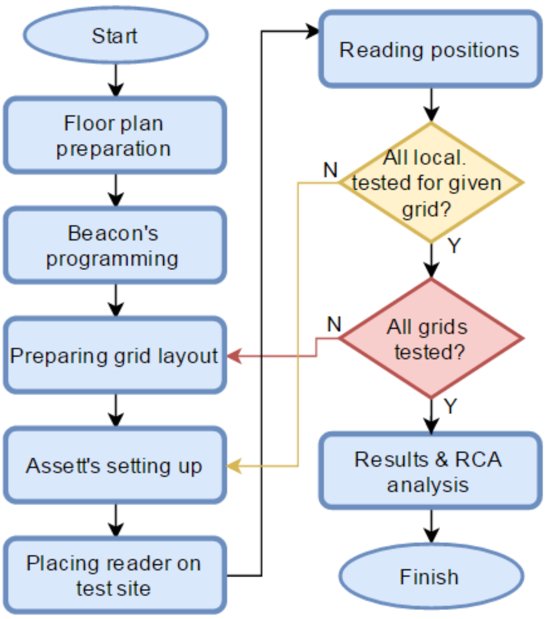

Figure 4. Research procedure for asset localization

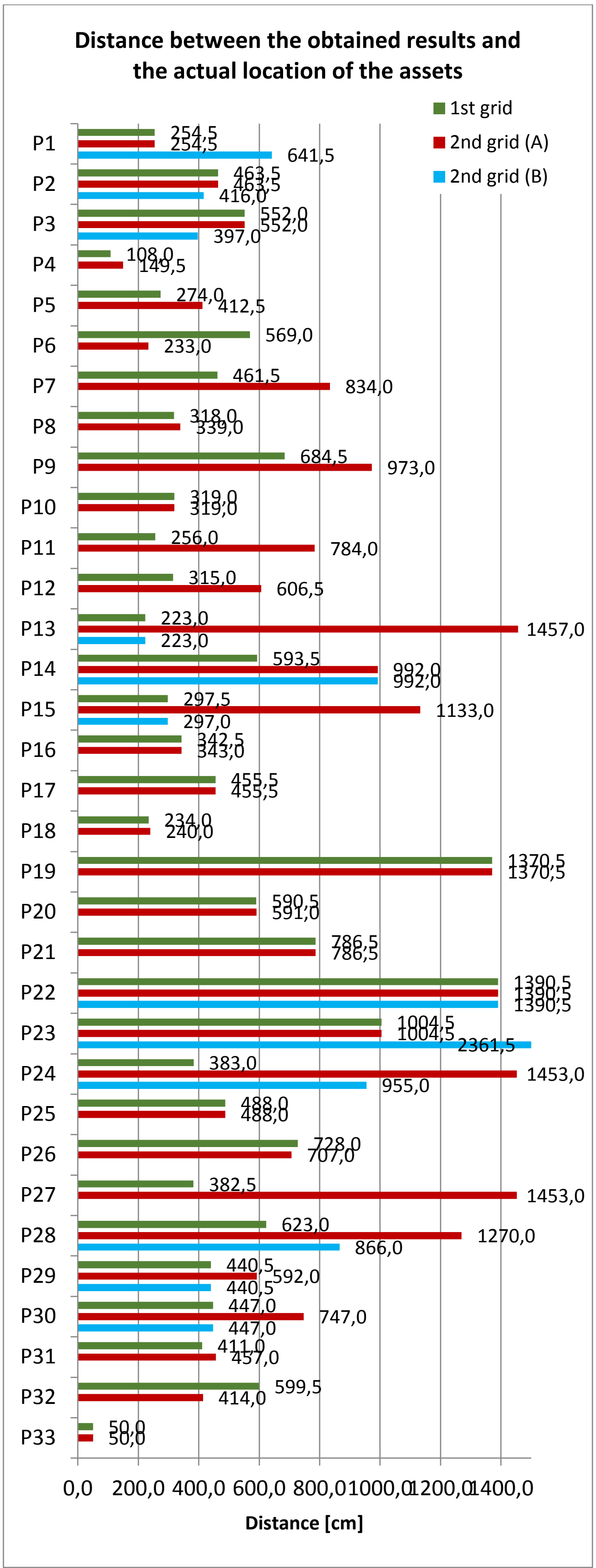

Figure 5. Distances between the results obtained in the tracking application and the actual location

4.3 Study results and discussion

Results of the performed analysis showed that during the measurements, there were four situations in which, for one placement of assets, the application returned two different results. Situation happened only at the second (concentrated) grid arrangement. Both results were analyzed and those obtained at the second grid arrangement for the first indications of the application, will be called Case A in the further discussion. Similarly, the set of results obtained at the second grid arrangement, taking the second indications of the application, will be called Case B.

In Figure 5 the distances between the actual location of the assets and those specified by the application was compared to determine the effect of change of the Beacons grid on the accuracy of the measurements.

The average measurement error from the performed study is:

- For the first grid laying - 497.5 cm
- For case A - 706.5 cm
- For Case B - 649.5 cm
- Total average - 618.0 cm

Authors analyzed results in detail to check if changing the grid (making it more dense) from 10,0m to 7,07m had any influence on the final results. It occurred that for the A case, the mesh density had a positive effect on the accuracy of three measurements, eighteen negative, while the twelve results remained unchanged. In case B the mesh thickening has had a positive effect on the accuracy of the five measurements, negative - seventeen, while eleven results remained unchanged. Results are presented in Figure 6.

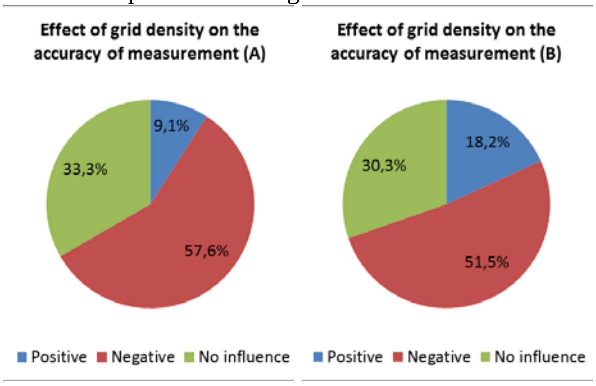

Figure 6. Change in grid density on the final results for Case A and Case B

It can be easily seen that changing the density(make it more dense) of the Beacon grid had negative effect on the measurement which means that the grid of 10,0 m was better that 7,07 m grid in terms of accuracy measurements. This clearly shows that analyzed system is not suitable for small areas, since it cannot provide enough precision in localization of the assets. It has to be also noted that even for first grid measurement error was at the level of 497,5 cm, what make it impossible to precisely indicate the asset position and limits possible application in process improvement methods.

After interviewing the Beacon producer it was also expected that the location of the search in the application would overlap with the Beacon location closest to the grid. The actual indications differed from the expected results depending on which grid (1st or 2nd) was used and analyzed. Figure 7 graphically presents this phenomena. Three criteria were used, which are below for better understanding how graph was prepared.

- Overlap/matching - the searched object was in the application at the point of the nearest grid Beacon.
- Does not overlap - the searched object was in the application at a point other than the nearest grid Beacon.
- The object is located between grid Beacons - the searched object was in the application at a point between two grid Beacons (not always closest).

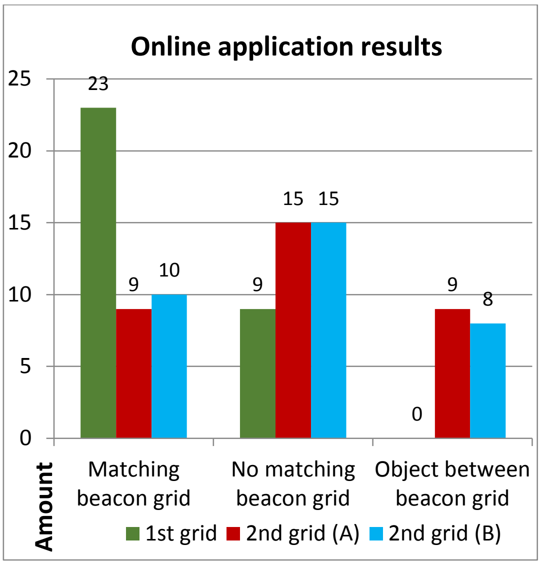

Figure 7. Beacons localization in the application compared to the grid position A and B

Figure 7 confirms that 1st grid had better precision that 2nd, since in 23 measurements Beacons indicated position of the closest grid point, while in the 2nd grid (denser) it was only 9 positions. Even the situation that for the 2nd grid 2 different cases (A and B) were received indicates, that the precision problem increased in this set up.

4.4 Root cause analysis

After reviewing obtained results it was decided to

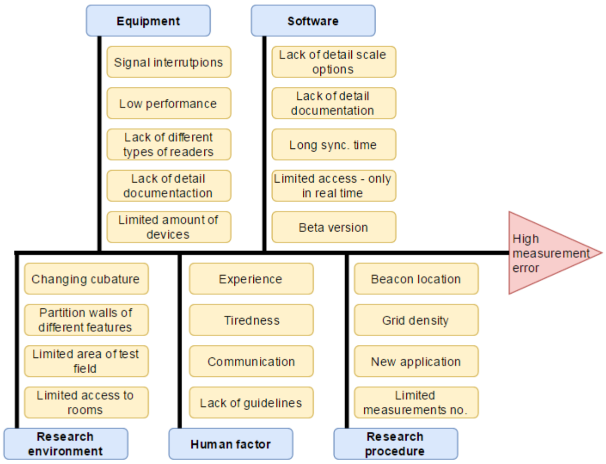

Figure 8. Ishikawa diagram prepared for high measurement error causes

	Problem	O	D	S	RPN
Equipment	Low performance	3	6	10	180
	Lack of different reader	5	1	3	15
	Signal interruptions	5	8	7	280
	Lack of detail documentation	9	1	2	18
	Lack of different types of readers	10	1	3	30
	Limited amount of devices	8	3	3	72
Environment	Changing cubature	8	1	4	32
	Partition walls of different features	4	3	4	48
	Limited area of test fields	5	2	4	40
	Limited access to rooms	3	2	4	24
Human f.	Tiredness	3	5	5	75
	Experience	7	2	4	56
	Communication	3	4	3	36
	Lack of guidelines	10	1	7	70
Software	Lack of detail documentation	5	1	6	30
	Long sync. Time	5	7	4	140
	Lack of detail scale options	9	7	3	189
	Limited access - only in real time	10	1	5	50
	Beta version	10	1	10	100
Procedure	Beacon location	5	4	2	40
	Limited meas. no.	2	2	2	8
	Grid density	6	5	8	240
	New application	10	1	8	80

Figure 9. FMEA analysis on the high measurement error

perform root cause analysis to find out what are the reasons for that situation and how they can be resolved in future studies. For this purpose Ishikawa diagram (Figure 8) was prepared with groups of couses and detail problems that were observed during the research procedure. Five main categories were defined: Equipment, Software, Research environment, Human factor and Research procedure. In each category precise problems were indicated.

After preparing the Ishikawa graph, FMEA analysis was performed to asses and decide which of the detailed problems had the highest influence on the received results (Figure 9). For this purpose 3 categories were selected: Occurrence, Detection and Severity, for which scale from 1-10 was adopted. For each category "1" indicated positive effect (respectively: never happened, easy to detect, no influence on the process), and "10" meant negative effect (always, hard to detect, huge influence on the process). Risk Priority Number (RPN) was then calculated by multiplying numbers in each category. In this way 3 the most important problems were defined, which are

- signal interruptions (RPN=280),
- grid density(RPN=240),
- lack of scale options in the software. (RPN=189).

Signal interruptions may be connected with the other devices using Bluetooth technology in the range of Beacons as well as walls and other physical obstacles in the range of Beacons. Grid density caused problem, since due to the building size it was difficult to introduce less dense grid. Lack of scale options is related to the precision of the measurements, since it should be able to precisely set the scale in the software before performing actual tests.

It has to be noted that tested system was never previously used in this kind of application thus observed problems may be corrected in the final version of the software and further research should be then performed with the analyzed Beacon technology.

5 Conclusions

Conducted analysis of the available literature with the focus on different RTLS technologies and performed study on the possibility of use BLE Beacons – Bluetooth devices as a locating systems allows to formulate the following conclusions:

- The construction industry is struggling with problems that can be resolved through the implementation of the Lean Management philosophy, resulting in resources savings, speeding up the construction process and waste removal.
- The Bluetooth based RTLS systems can be useful device in construction sector even taking into account its limitations.
- The measurement error for the grid of 10m was 497.5 cm, which significantly limits the usefulness of the system for precise localization, but opens possibilities for location on the bigger area.
- Denser Beacon grid results in less accurate measurement results for analyzed cases.
- 3 the most important problems have influenced such results were defined: signal interruptions, grid density, and lack of scale options in the software.
- Most suitable stage for using RTLS systems in productivity improvement is measure step, where they can be used as a tool for data acquisition.

The purpose of the study was also to check the suitability of the system in construction industry. Based on the obtained results, it is proposed to use this type of the systems to locate large scale objects where the exact location of the object is not required, but only the approximate location, such as the area in which it is located. The potential for using the system to track employee traffic has also been noted, assuming that in the future system will be equipped with the additional options based on the access to historical data.

It has to be also noted that one features of Beacons is the possibility of sending specific messages to smartphones within its reach. Authors are of the opinion that this feature can be useful in construction industry, especially in the area of alerting people on site of dangerous areas, transmitting health and safety instructions, etc. Therefore, it is also suggested to test equipment in this respect.

Authors plan to perform further research in the area for the possibility of use of RTLS in construction sector, for the purpose of process improvement, since those systems are response to the need of data acquisition necessary for performing Lean Management methods and improvements. What is further tests should be performed on final version of the analyzed Beacon software, as improvements might influence in positive manner on the final results of further tests.

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