LEVERAGING PASSIVE RADIO FREQUENCY IDENTIFICATION TECHNOLOGY IN HIGH-RISE RENOVATION PROJECTS

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ABSTRACT

The hypothesis is that leveraging automated data collection technology for site status analysis would play a more significant role in advancing decision making in construction projects if applied to traditional labor intensive management work tasks such as manual data record keeping, progress tracking measurements, and reporting of daily work tasks and process flows; and further, if applied in distributing information back to decision makers including the field management and workforce level. This paper will demonstrate results to the design, development, and furthermore and mainly, the effective and very affordable implementation of a state-of-the-art wireless passive RFID based technology system that collects and distributes information from and to decision makers. The developed technology was tested for several consecutive months on more than 50 construction workers, material carts, personnel and material lifts, and construction material items that were critical in a high-rise building renovation project.

Recent research on material tracking, has demonstrated that the implementation of material tracking technology is feasible. Studies have yet to demonstrate whether the same or other technology can be used on other resource types, including workers, and furthermore in advancing technology that works bi-directional: (1) collect and analyze data, and (2) return feedback or other information to the decision makers. Despite a rigorous cost-benefit, hardware reliability and safety tests, implementation of technology in field operations is often performed on an as-needs basis. Project based case studies are effective research tools to measure the benefits and barriers that technology comes with. This paper defines key metrics to measure success in the phases of data collection, the signal and data processing, and in the use of newly generated or already available information for advanced decision making based on passive RFID technology.

Keywords: RFID; productivity; renovation project; workforce, material, and workforce tracking; automation..

1. INTRODUCTION

Until recently, labor productivity has been analyzed manually requiring time-consuming work and the possibility of human error (Oglesby 1988, Goodrum 2006). Past research has also shown the multitude of benefits obtained from implementing radio frequency identification (**RFID**) technology within various construction sites including asset tracking, inventory management, and on-site security upgrades (Ergen 2007, Grau 2009). Projects with higher automation and integration of information technology improved between 31% to 45% in productivity. In material tracking studies, the use of RFID allowed laborers to locate materials with an improvement ratio of 8:1 over manually tracking. RFID implementation in an outdoor environment led to a 4.2% increment in steel erection productivity.

Additional construction improvements can be identified in terms of productivity analysis of work crews, material transport, and the overall approach to a project to determine whether the construction process is operating at maximum efficiency or can be adjusted to improve its effectiveness. In particular, labor productivity of workers is an important area to maintain for completing a project on schedule. A large percentage of construction costs come from the quantity of labor hours spent completing the desired tasks. Thus, by maximizing labor productivity, companies can avoid additional costs from falling behind schedule. Many factors determine whether workers are able to complete their tasks at the necessary pace such as experience, age, skill, motivation and leadership of the workforce. Appropriate work conditions such as job size and complexity, site accessibility, labor availability, equipment use, and local climate each influence the entire operation (Hendrickson 2008).

The research scope focused on a high-rise renovation project. The general contractor and its subcontractor had to replace 6,350 windows within a 15 month project duration. A lack of open space at the base of the high-rise made the use of cranes unreasonable as the outriggers would have extended into the street blocking traffic. In order to meet the needs for the glass replacement, one set of two buck hoists had been placed at the street elevation which then rose to the 16th floor platform where a second set of two additional buck hoists was located to carry workers and equipment to up to the 73rd floor. The payload capacity of the hoists was over 4,000 pounds and provided transportation for large materials with complete accessibility to each floor of the building. Height (or length) of a building in construction largely affects the efficiency of lifting (or moving) equipment installed on-site thus affecting the overall project schedule (Lee et al. 2008).

This paper presents the results of implementing passive radio-frequency identification technology and provides a study of labor productivity analysis for a window replacement project on a high-rise construction site. This study provides detail studies to track the efficiency of a buck hoist worker and material lift system for transportation and illustrates the applicability of the technology despite the presence of numerous signal impeding obstacles located throughout the site. These issues are resolved with an effective automated location and time tracking system that works in both an indoor and outdoor environment simultaneously with a data recording software and database. The in-house development of a database allows for timely information retrieval of various items of interest in this study and requires less. Experimental results show that RFID technology has the capacity to work and produce useful data for labor productivity purposes in an ever-changing construction environment. The research further recognizes relevant information regarding system optimization and worker feedback for future use.

2. BACKGROUND

2.1 Lifting and Hoisting in High-Rise Construction

The tower crane is the most commonly used equipment that is available to the construction sites for hoisting. With roots tracing back to the Roman Empire, cranes are easily identified on a construction site. Anchored by bolts to large concrete pads or facades, this freestanding massive piece of equipment can safely reach any height of a building. As with any other construction process, pre-planning of the location, functionality, and cost of the tower crane determines whether it is a viable option for vertical and horizontal material hoisting on a jobsite. Multiple variables must be considered when exploring whether to install a tower crane including space limitations. The tower crane structure has the distinct advantage of taking up a relatively small amount of space on the ground with respect to the height that it can reach. The horizontal arm of the tower crane, or jib, must be considered when dealing with space restrictions. While it is not affected in large open areas, horizontal planning does need to take place in densely constructed cities where other large structures must be avoided by the swinging of the jib. The contractor plans on devoting a large portion of the surrounding area on the ground as restricted areas for safety as well as laydown areas for materials (Everett 1993, Pertulla 2006, Pan 2007). Another issue to consider is time. The time that it takes to swing the jib to the pick location, attach the rigging to the object being lifted by the crane, safely lift and maneuver the material to the appropriate floor, set down the item, unhook rigging, and then repeat the cycle depends highly on the efficiency and experience of the crane operator and specifications of the machinery. With major time losses equaling a loss in money, it is very important to plan the operations ahead of time and take actions to mitigate problems during the daily operations of the crane in order to avoid time lost and additional incurred costs. Overall, a tower crane is an essential asset to large scale vertical construction project. However, it can prove costly with time delays and maintenance throughout all phases of construction as well as impractical due to space requirements.

Thousands of tower cranes are currently employed around the world and are generally regarded as a major item of equipment on high-rise building sites. While tower cranes possess large lifting capacities, operational inefficiencies exist causing time delays and miscommunication results in scheduling and safety issues (Everett

1993, Wang 2008, Pertulla 2006, Pan 2007). Efficient planning and preparation is vital to maximizing productivity as single lifting cycle times can surpass twenty minutes in a building consisting of 40 stories. Lee et al. (2006) developed a tower crane operating system which uses wireless video control and RFID technology to provide real-time visual images, details of materials waiting to be lifted, and the locations for installation. Based on a case study using the new operating system, benefits including increases in work speed, greater communication, and improved safety were realized. Robotic tower cranes are proposed (Chang-Yeon et al. 2009) and are expected to have key advantages in construction scheduling, labor and material costs, and improvement in safety. By using a series of laser devices, GPS, encoder, accelerometer, and other devices, improvements in productivity between 10%-50% are expected. However, poor weather conditions such as rain or snow make this type of crane technology inoperable and thus irrelevant in many regions of the world. The focus on buck hoist operations in high-rise construction has been neglected.

2.2 RFID Technology in Construction

Radio frequency identification (RFID) systems, classified as active (battery powered) or passive (without battery), are composed of a transponder and transceiver coupled with an antenna which gathers and transmits information without the need of a direct line-of-sight to the tags. The antenna emits radio signals through the transceiver which begins communication between it and the transponder. Tag data such as a unique identification number can be read and processed use. While bar code systems are limited due to line-of-sight, durability, and read-range constraints, RFID technology provides significantly greater read-ranges and works under rugged outdoor and indoor conditions including in temperatures from -40°C to 200°C. Ross et al. (2007) tested passive ultrahigh frequency tags for durability of RFID tags in various harsh conditions and found the tags were durable enough to work despite the existence of extreme moisture, pH, temperature, and pressure.

Active RFID has been previously tested in construction. Active RFID technology can simultaneously and uniquely recognize facility items, store information regarding maintenance history of these items, and continuously update the information in real-time (Ergen 2007, Grau 2009).

The benefits of passive RFID tags derives from a reduced cost as they are powered from the transceiver eliminating the need for an onboard battery. Thus passive tags are exceptionally small in size and have an extended operational life (Ross 2009). Little research on passive RFID in construction has been done. The cost of passive RFID tags is inexpensive at roughly $0.20 a piece (see Figure 1). Passive RFID tags possess small data storage capacities of roughly 128 to 256 bytes which can be hyperlinked to other information but are unable to be updated and have no self-reporting capability. The read ranges of passive tags currently reaches currently around four to ten meters. However, performance is reduced in close proximity to any metal surface as the metal causes signal attenuation (Vogt and Teizer 2007).

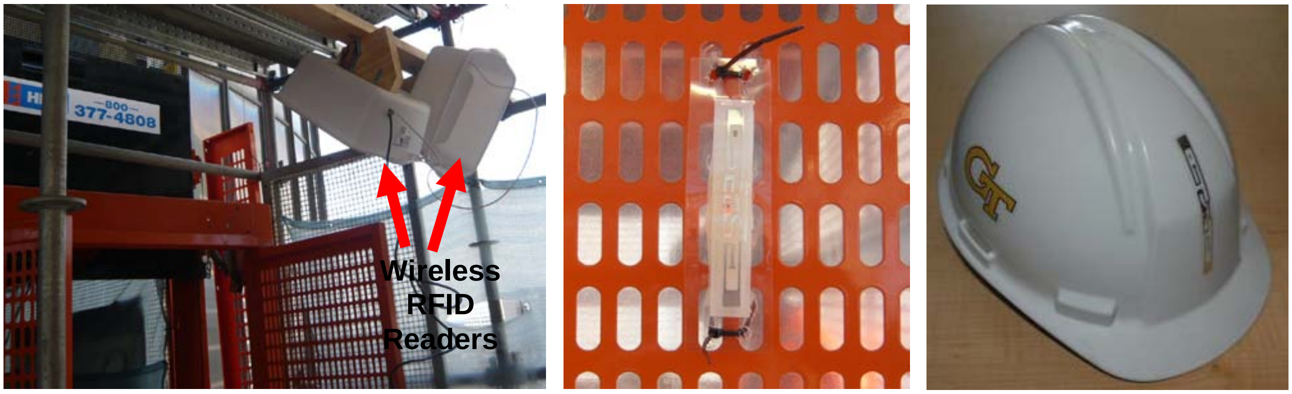


Figure 1: Wireless RFID reader on 16th floor, and passive RFID tags installed on buck hoist and worker helmet.

3. RESEARCH OBJECTIVE AND METHODOLOGY

The goal of this research is to prove that RFID technology installed within a construction site can draw important information to aid in improving labor productivity and help insure that time wasted during construction is minimized. Past research has shown that RFID is valuable in material and tool tracking as well as eliminating time spent with manual data entry. In this paper, each of the workers, materials, and elevator buck hoists on-site will be tagged with passive RFID tags to analyze the efficiency of the multiple buck hoist system installed on the exterior of the building for worker and material transport. This RFID technology linked with Microsoft Visual Basic software will record exact times for worker and material movement throughout the high-rise and will illustrate the effectiveness of the buck hoist system rather than other means of inventory transport in commercial construction.

In order to improve the labor productivity of a high-rise construction project with the use of an exterior material hoist (see Figure 2), wireless passive radio-frequency identification technology was implemented at specific locations within the high-rise construction site. Workers, lifts, material transport carts, and windows were tagged with unique passive RFID tags and tracked in real-time by strategically placed RFID readers. By placing tags on each buck hoist, time studies can be conducted and data analyzed to determine the amount of time spent waiting for lifts to arrive for pick-up and delivery of workers and materials. The use of RFID will exhibit the benefits and drawbacks of the buck hoist material and personnel lift system in a high-rise construction setting. Experiments will determine whether a high-rise building can support and benefit from the implementation of the technology as well as the decision to use a buck hoist system for material transport. The ability of the technology in this work environment will be shown after implementing the necessary means for acquiring sufficient data, conducting analysis of the data, and identifying the problem or areas with room for improvement. The site of the experiment in downtown Atlanta serves as an excellent case study as it involves a 73 story structure composed of concrete and metal located in a densely populated city. Experiments will show various factors affecting the construction process and whether RFID technology has the capacity to improve labor productivity analysis despite the presence of signal inhibiting materials.

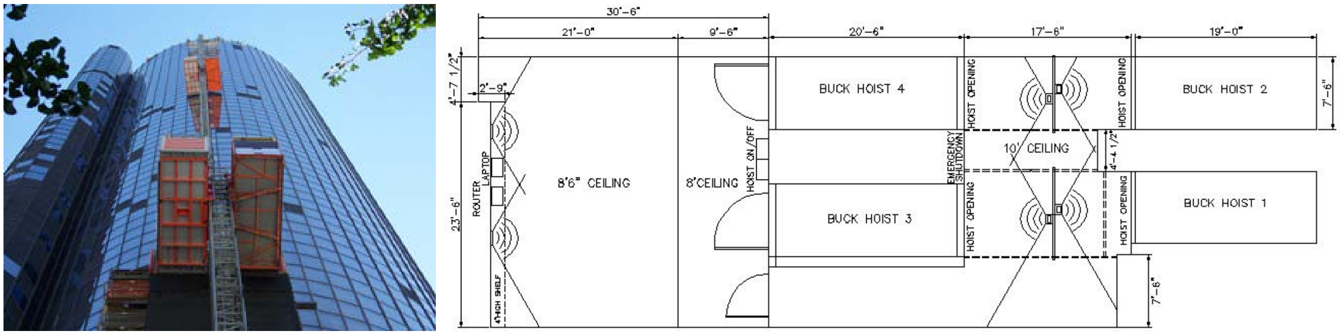


Figure 2: Two pairs of buck hoists from ground to 16th floor and to upper floors (left) with strategically placed Gen 2 RFID readers on 16th floor and each work floor (right).

4. FIELD TRIALS AND PRELIMINARY RESULTS

4.1 Hardware and Software Technology

The first step in implementing the developed wireless passive RFID tracking system was to issue each worker, material cart, replacement window, and buck hoist one or multiple unique RFID tag. Each construction worker was issued two unique RFID tags for redundancy. One RFID tag is placed on outside front of the helmet while the other tag was placed inside the rear of the helmet. Each tag was given a unique ID number in order to help maximize detection and to allow data collection to tags that could not be read. In addition, signal strength between the two tag locations on helmets were measured to identify the best possible location of passive RFID tags on helmets. Additionally, each buck hoist had eight RFID tags attached to its entry doors. Four tags were placed on each of the front and back entrances to maximize detection in a metal platform environment. These tags occupy each corner of the hoist door facing the incoming radio frequency signals from the antennas. Glass that was destined for replacement has arrived at the construction site in large wood-framed batches, and was separated into groups of six. Each batch was tagged with a single unique RFID tag. Furthermore, the setup of the tracking technology consists of strategically placing six of the radio frequency readers, and two mobile laptop computers with wireless access to the RFID readers. The actual glass replacement process and work zone consisted of five floors at a time. Actual work took place on the middle of three floors while the outer two floors were used primarily as buffer zones to control construction noise that may affect guests in the high-rise hotel.

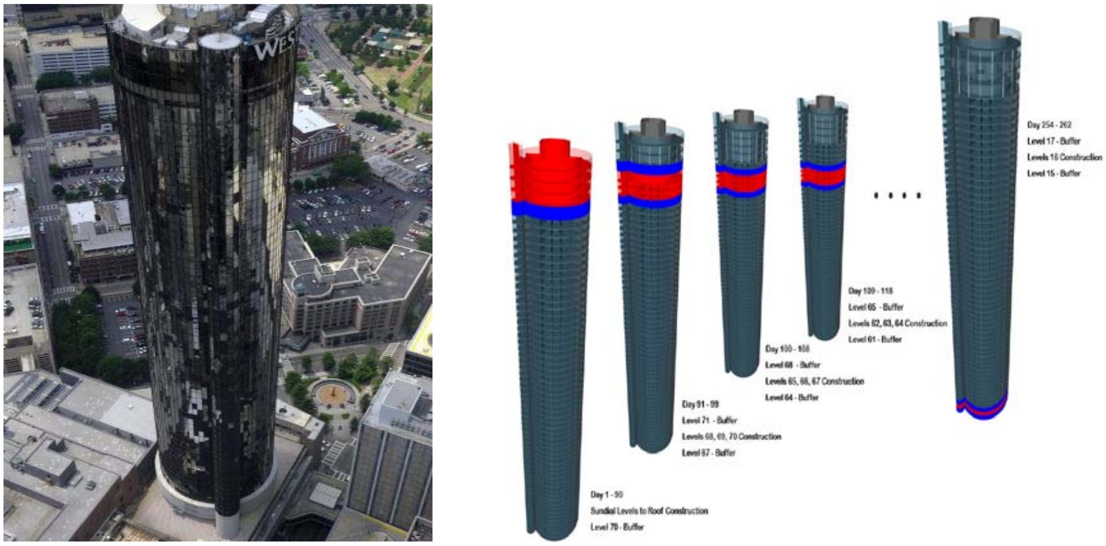
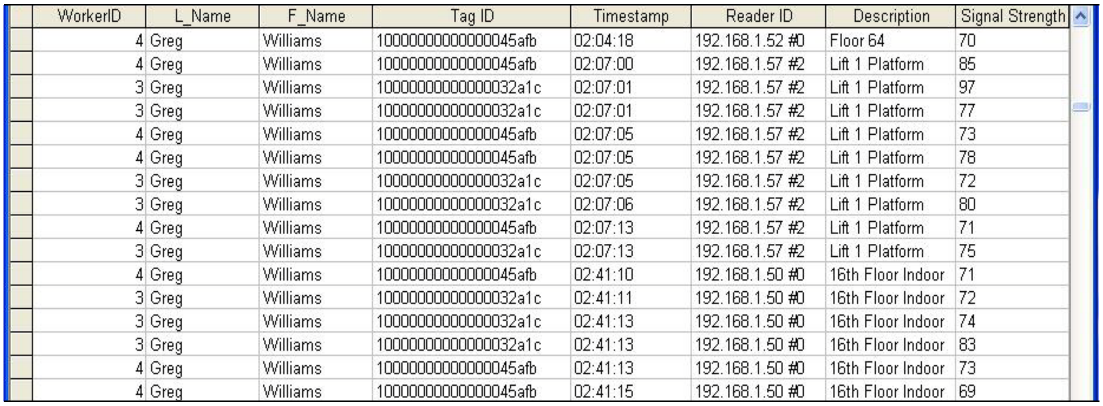


Figure 3: Work Sequence and Buffer Zones in the High-Rise Building (Courtesy: Skanska USA Building Inc.)

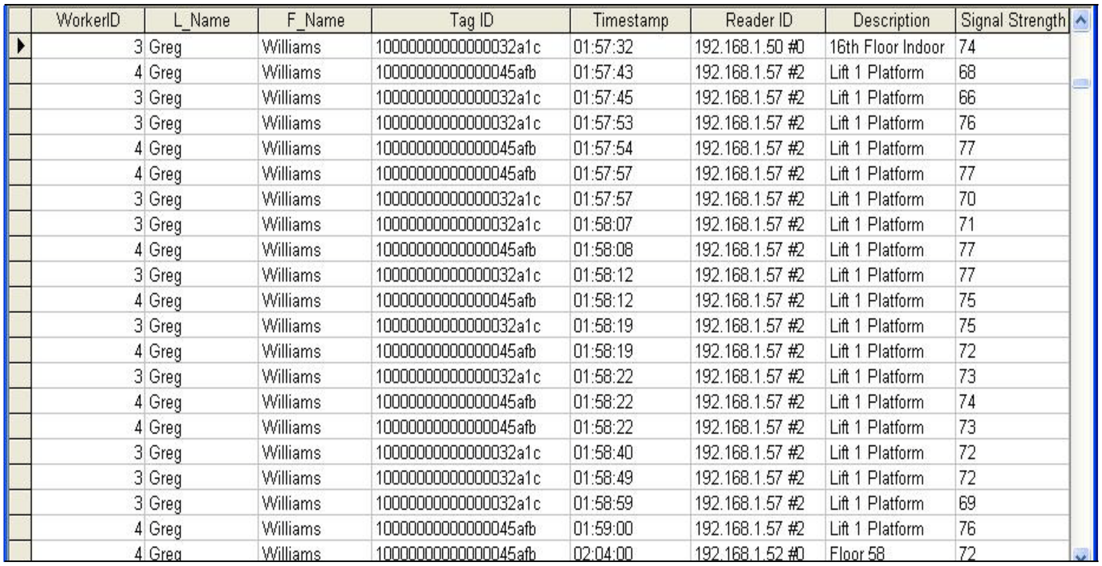
One reader was placed on each of the three work floors and faces the entrance of the buck hoist. Each antenna reader had a particular IP address that was used for identification and allowed the database to display locations of the RFID tags when they appeared in the work floor. The antenna readers were connected wirelessly via a Wireless Local Area Network (WLAN) through an onsite router, then to the laptop computer that was used to store the collected data. The wireless routers on site have enough signal strength to penetrate five concrete slab floors. The same connection methodology is implemented on the sixteenth floor of the high rise building. The primary reason for deploying two separate systems is because it was tested impossible for a single router to broadcast a signal from the sixteenth floor to the top floors of the building; with a maximum separation of fifty floors. Two readers were located on the platform of the sixteenth floor with auxiliary add-on antenna extensions. These add-ons were used to increase the range and visibility of each of the readers that they were connected to. The extended add-ons also allow the antenna readers to have a field-of-vision of 120 degrees, rather than the limited 60 degree scope of a single reader. The third step to set up the wireless system was to successfully connect the antenna readers with the laptop computers. Each laptop computer had installed software that was developed by the authors. The software allows the acquisition of data that consists of: (a) RFID tag ID, (b) read frequencies, (c) time of read instance, (d) signal strength and link quality indicator, and (e) antenna reader internet protocol (IP) address. The final step was to begin the data collection. Recorded data was stored as either an undesignated file type or text file format. Readings from the antenna readers occurred at the default read rate of the readers is set to 100Hz and was set to record during regular work times (6 a.m. to 8 p.m. on any day to compensate for overtime and weekend work).

In order to store and tabulate data recorded by the RFID readers, an interface consisting of information from a database within Microsoft Access in combination with Microsoft Visual Basic was created. The purpose of developing a database is to make the information that has been tracked by the RFID readers easily accessible to a project manager. The manager can choose specific data and retrieve results with any relevant information. For this research, the database was created to store information regarding the movement of workers, lifts or hoists, carts, and glass. Figure 4 illustrates a sample data set that becomes available when linking recorded information of the passive RFID system.



WorkerID	L_Name	F_Name	Tag ID	Timestamp	Reader ID	Description	Signal Strength
4	Greg	Williams	10000000000000045afb	02:04:18	192.168.1.52 #0	Floor 64	70
4	Greg	Williams	10000000000000045afb	02:07:00	192.168.1.57 #2	Lift 1 Platform	85
3	Greg	Williams	10000000000000032a1c	02:07:01	192.168.1.57 #2	Lift 1 Platform	97
3	Greg	Williams	10000000000000032a1c	02:07:01	192.168.1.57 #2	Lift 1 Platform	77
4	Greg	Williams	10000000000000045afb	02:07:05	192.168.1.57 #2	Lift 1 Platform	73
4	Greg	Williams	10000000000000045afb	02:07:05	192.168.1.57 #2	Lift 1 Platform	78
3	Greg	Williams	10000000000000032a1c	02:07:05	192.168.1.57 #2	Lift 1 Platform	72
3	Greg	Williams	10000000000000032a1c	02:07:06	192.168.1.57 #2	Lift 1 Platform	80
4	Greg	Williams	10000000000000045afb	02:07:13	192.168.1.57 #2	Lift 1 Platform	71
3	Greg	Williams	10000000000000032a1c	02:07:13	192.168.1.57 #2	Lift 1 Platform	75
4	Greg	Williams	10000000000000045afb	02:41:10	192.168.1.50 #0	16th Floor Indoor	71
3	Greg	Williams	10000000000000032a1c	02:41:11	192.168.1.50 #0	16th Floor Indoor	72
3	Greg	Williams	10000000000000032a1c	02:41:13	192.168.1.50 #0	16th Floor Indoor	74
3	Greg	Williams	10000000000000032a1c	02:41:13	192.168.1.50 #0	16th Floor Indoor	83
4	Greg	Williams	10000000000000045afb	02:41:13	192.168.1.50 #0	16th Floor Indoor	73
4	Greg	Williams	10000000000000045afb	02:41:15	192.168.1.50 #0	16th Floor Indoor	69

Figure 4: Sample data of two corresponding tags to one worker (worker ID, Name (anonymized), passive RFID Tag ID, Timestamp [HH:MM:SS], RFID reader ID, reader description, signal strength of reading).



WorkerID	L_Name	F_Name	Tag ID	Timestamp	Reader ID	Description	Signal Strength
3	Greg	Williams	10000000000000032a1c	01:57:32	192.168.1.50 #0	16th Floor Indoor	74
4	Greg	Williams	10000000000000045afb	01:57:43	192.168.1.57 #2	Lift 1 Platform	68
3	Greg	Williams	10000000000000032a1c	01:57:45	192.168.1.57 #2	Lift 1 Platform	66
3	Greg	Williams	10000000000000032a1c	01:57:53	192.168.1.57 #2	Lift 1 Platform	76
4	Greg	Williams	10000000000000045afb	01:57:54	192.168.1.57 #2	Lift 1 Platform	77
4	Greg	Williams	10000000000000045afb	01:57:57	192.168.1.57 #2	Lift 1 Platform	77
3	Greg	Williams	10000000000000032a1c	01:57:57	192.168.1.57 #2	Lift 1 Platform	70
3	Greg	Williams	10000000000000032a1c	01:58:07	192.168.1.57 #2	Lift 1 Platform	71
4	Greg	Williams	10000000000000045afb	01:58:08	192.168.1.57 #2	Lift 1 Platform	77
3	Greg	Williams	10000000000000032a1c	01:58:12	192.168.1.57 #2	Lift 1 Platform	77
4	Greg	Williams	10000000000000045afb	01:58:12	192.168.1.57 #2	Lift 1 Platform	75
3	Greg	Williams	10000000000000032a1c	01:58:19	192.168.1.57 #2	Lift 1 Platform	75
4	Greg	Williams	10000000000000045afb	01:58:19	192.168.1.57 #2	Lift 1 Platform	72
3	Greg	Williams	10000000000000032a1c	01:58:22	192.168.1.57 #2	Lift 1 Platform	73
4	Greg	Williams	10000000000000045afb	01:58:22	192.168.1.57 #2	Lift 1 Platform	74
4	Greg	Williams	10000000000000045afb	01:58:22	192.168.1.57 #2	Lift 1 Platform	73
3	Greg	Williams	10000000000000032a1c	01:58:40	192.168.1.57 #2	Lift 1 Platform	72
3	Greg	Williams	10000000000000032a1c	01:58:49	192.168.1.57 #2	Lift 1 Platform	72
3	Greg	Williams	10000000000000032a1c	01:58:59	192.168.1.57 #2	Lift 1 Platform	69
4	Greg	Williams	10000000000000045afb	01:59:00	192.168.1.57 #2	Lift 1 Platform	76
4	Greg	Williams	10000000000000045afb	02:04:00	192.168.1.52 #0	Floor 58	72

Figure 5: Worker wait and travel time for elevator.

4.2 Preliminary Results

The value of producing a database is evident from the ability to select specific data from a variety of options for data analysis. The best practice is to give a consultant or staff member adequate time to find valuable productivity data and prepare the necessary steps to implement changes for improvement. Automating the analysis of recorded data saves significant time when examining labor productivity. In a high-rise construction setting consisting of workers, manually performing time studies is an inefficient and lengthy task. Thus the need for an automated data analysis tool is necessary to produce valuable time study results in a timely manner.

Depending on the desired information, supervisors or managers can conveniently edit this table to store additional information. Other important information such as weather can be linked to queries by date to assess if weather conditions factored into the results obtained by the readers. Also, each reader has been programmed to record timestamps for the exact moment in which the tag was read.

4.2.1 Tracking Workers

The example in Figure 4 shows that the time it takes a worker (or any resource the tag is attached to, e.g., equipment or material) to use a buck hoist can be recorded. Figure 4 displays the results to consecutive tag readings of a worker that left from the 64th floor at 2:04:18 P.M. and arrived at the 16th Floor Platform at 2:07:00 P.M. These two timestamps can be used to find the travel time for this distance which is calculated to be 2 minutes 42 seconds. Since tags are continuously being recorded when in close proximity to a reader, it is possible to use this analysis tool to find additional information such as the time lost when a worker is waiting for a lift to arrive. In this instance the worker was walking inside the building once the worker arrived on the platform level.

Figure 5 depicts a scenario that can be utilized for productivity measurements. In this case, the worker walked outside of the building on the 16th floor 01:57:32 P.M. and waited on the platform for 1 minute 17 seconds before leaving the platform at 01:59:00 P.M. The worker then arrives at his desired location, Floor 58, at 02:04:00 P.M. which calculates that this hoist took the worker 7 minutes 17 seconds to reach the desired location. This tool allows productivity analysis to be conducted without the need for positioning multiple people throughout the site to record timestamps of specific workers or issues related to manual data entry errors.

4.2.2 Tracking Equipment

Manual observations make it possible to document applicable data about which buck hoists are utilized most often. Through the implementation of the previously described RFID data collection system, the location of the four buck hoists on site were tracked and documented. Utilizing the developed RFID system makes it possible to collect and analyze raw data automatically.

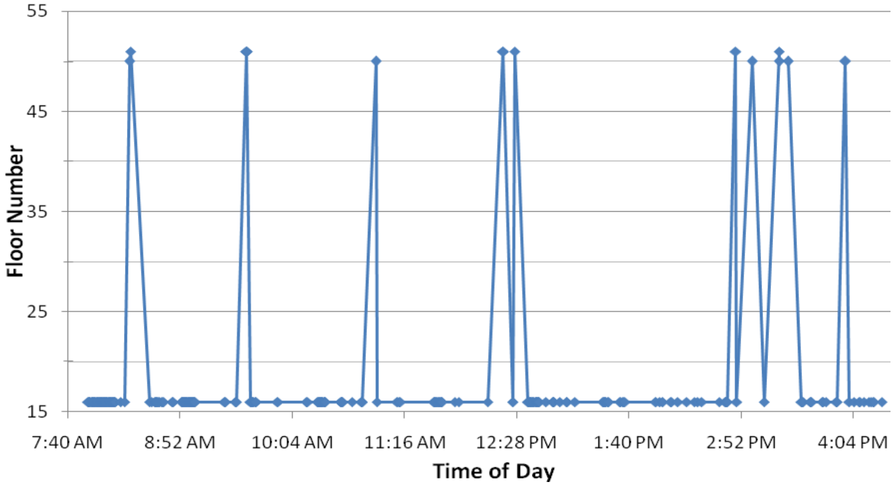


Figure 6: Worker wait and travel time for elevator.

Buck hoist #3 was the primary method of transportation from the 16th floor, the main staging platform, to the upper three working floors. Four wireless RFID readers were installed on the staging platform the entry and exit to each buck hoist individually. One wireless RFID reader was installed on each of the three working floor. As the working floors moved overtime, so were these three readers redistributed on each working floor. Buck hoist #3 was selected for the data analysis, as it was utilized the most and provided the most consistent data. Over a typical working day, the buck hoist made several trips to the upper floors to bring or pick up workers, equipment, and/or materials to their working destination. The movements of the buck hoists were recorded on a continuous work day basis, even on weekends that had no working action. With longer spans of data, such as a weeks or months, more observations were performed and allowed for more accurate conclusions. Figure 6 shows the travel patterns of buck hoist #3 over one complete (sample) working day. Floor sixteen is the start point of the buck hoist while floors 49 to 51 were the working floors during this day. Based on the data analysis that can automatically synchronize the passive RFID tags of workers, equipment or materials, cycle times and usage of the buck hoist can be calculated. Data to wait times, peak times and underutilized times can be recorded and utilized.

A particular important piece of information for project managers that resulted from the data analysis is the cycle time of the buck hoist, including its cycle times per day, week, month, and even over the entire project. The average cycle time of a worker on April 15 to go from the 16th to the 50th or 51st floor, then loading workers or materials, and then returning back to the 16th floor was 8 minutes 24 seconds. Compared to other days, the average amount of time the buck hoist was in use on a typical working day during the week of April 26 to April 30 was 2 minutes 30 seconds. Such information can play a vital role in decision making. It helps construction managers allocate resources, keep project schedules on time while improving efficiency, all of which save time and money.

Knowing the amount of time spent idle and at what floor of the project can help with more effective planning and project management. The developed data analysis system allows to measure the time that a buck hoist is in idle position. Over a typical work week, buck hoist #3 spent 1 minute and 30 seconds idle at the 16th floor. The 16th floor is the default location for the buck hoists to remain in idle position. The buck hoists sometimes stay also idle on upper floors; for example, during the week April 26 to April 30, buck hoist #3 spent on average 41 minutes 5 seconds in idle position on the upper floors.

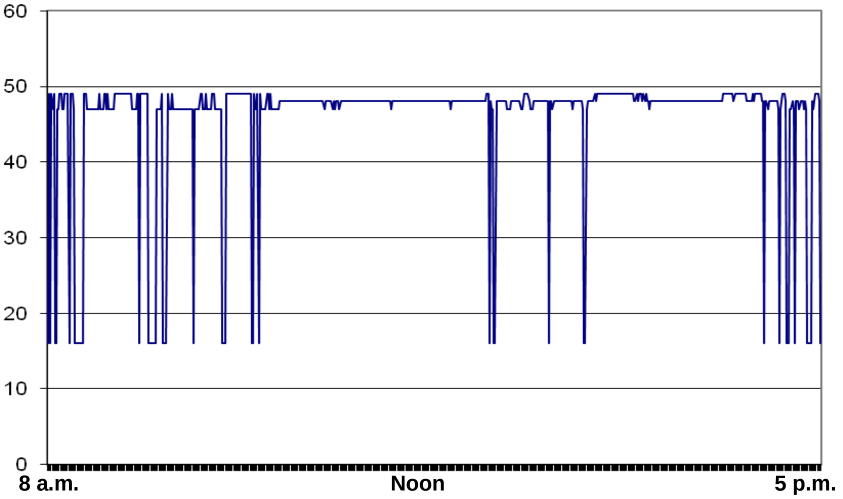


Figure 7: Buck hoist remaining primarily on top level floors.

On certain days of the week, the tower on which the buck hoist operates will experience servicing and maintenance downtime. During these times, the buck hoist remains primarily on the top working floors and rarely makes any trips to the 16th floor. Figure 7 shows a day in which the top parts of the buck hoist tower is being disassembled, and inactivity of the buck hoist.

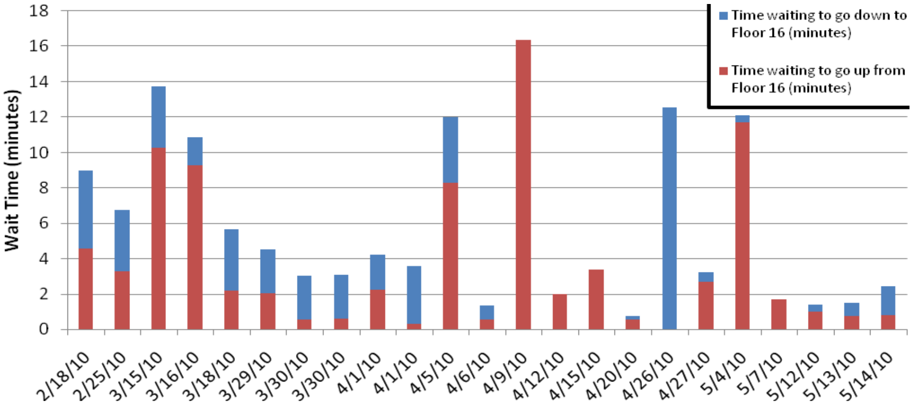


Figure 8: Worker wait time for service elevator.

On some working days on the critical path, workers and materials had to be corralled into a service elevator that was shared with hotel employees on the site. During these days, wait times for vertical transportation on the site significantly increased, leading to project delays and tension among the subcontracted workforce who were hindered in performing their tasks. Figure 8 shows the service elevator wait times during such sample days. In the pessimistic case, it took more than 16 minutes of wait time for the service elevator to arrive. The service elevators inside the building held less weight, and thus less workers and materials. With work tasks being on the critical path and thus highly dependent on each other, work progress was observed to slow down. Overtime and weekend work was performed to compensate for any delays and to take advantage of better than expected weather conditions.

4.2.3 Tracking Material

Glass was the major material that was moved among the site. Since the construction project was a glass removal and replacement job, the essential tasks revolved around the transportation of the glass when it arrived on site. A passive RFID tag was placed on the glass upon arrival at the street level of the job site.

The placement of the tag on the glass was important in itself, as the thickness of the glass prevented some RFID tags from being recognized by the readers. The sample of cycle times varied over different delivery dates, and was mostly influenced by the floor that it was hoisted to and the time that the glass delivery truck arrived. Cycle times did remain very similar to normal cycle times for the buck hoists, only adding a few minutes to account for loading and unloading the glass carts. A graph would look similar to Figure 6.

4.2.4 Assessment of Passive RFID Technology

One concern when implementing a RFID system on a construction site is ensuring the signals from passive RFID tags can be effectively transmitted and received. To overcome radio frequency signal interference issues, all four buck hoist were equipped with several passive RFID tags. Each hardhat of a worker was labeled with two inexpensive passive RFID tags. One of which was placed on the front of the hard hat, and the other was placed on the inside towards the back of the hard hat. With each passive RFID tag having their own unique ID, their readability can be analyzed and used as reference for future studies. Figure 8 shows the location of two passive RFID tags mounted on front side and the rear inside of a hard hat. Since the passive RFID tag does not carry any battery, its adhesive and flexible label can very easily be attached to a hard hat. The readings show that the location of passive RFID tags at the front (Figure 9, left image) and rear (Figure 9, right image) of a helmet have little to no role in reading the passive RFID tag via the developed wireless passive RFID reader system. Redundant information from multiple passive RFID tags was preferred, but duplicate data can be easily filtered.

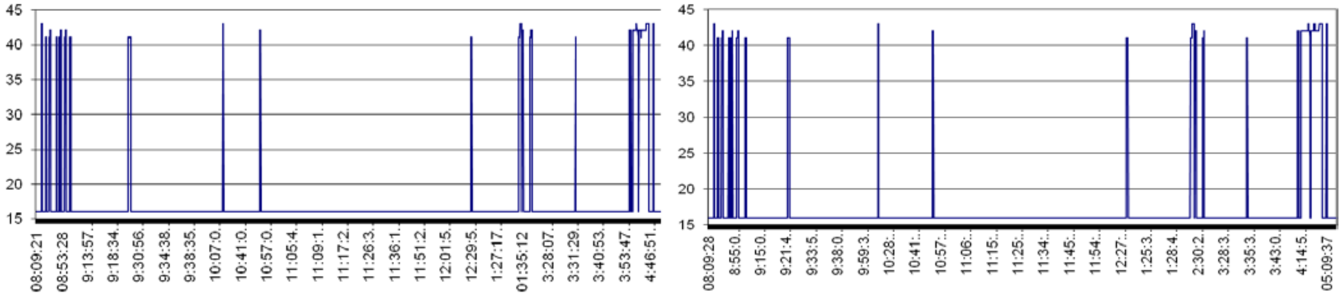


Figure 9: Close similarity of readings of RFID tags mounted at the front (left) and rear inside of a helmet (right).

5. CONCLUSIONS AND RECOMMENDATIONS

Active RFID technology has been proven through past research to benefit the construction industry in various outdoor environments. Preliminary results shown in this paper prove that passive RFID technology can be successfully implemented and used to record important productivity data within an indoor construction environment despite the vast height of the structure and the presence of concrete and metallic elements. Furthermore, signal strength data shows that passive RFID tags can be read by readers whether placed on the exterior or interior of a hard hat. It is suggested for future use that passive tags should be embedded in the interior of the hard hat to reduce tampering by workers. In the past, analysis of labor productivity through manual data collection has required substantial amounts of human labor hours and is prone to human error while the implementation of RFID can greatly improve the accuracy of productivity analysis. The use of a database also shows to benefit staff members' time for preparing manual documents. The analysis conducted in this research showed that the buck hoist system, while less time efficient in material transfer than the commonly used tower crane in high-rise settings, is a sufficient means of transportation for larger work crews of fifty or more people. Efficiency studies such as buck hoist availability become feasible utilizing the passive RFID system. Data demonstrated in this paper shows that lift availability depends on work tasks scheduled during the day. Future research should focus on fully automating the data transfer process from the jobsite to a database for site operation and scheduling analysis. Other future studies should focus on the impact of technology on humans, for example, understanding workers' motivation to participate in RFID studies and in particular when RFID tags are deployed on their hardhats. Overall studies may be performed on understanding how all project stakeholders (including workers) can benefit from using advanced sensing technology in the field. Technical studies should be conducted to how passive RFID technology and in particular the read distance of passive RFID tags can be improved. In summary, this paper has discussed the initial feasibility of leveraging a passive RFID system that comes at affordable cost in a high-rise renovation setting.

ACKNOWLEDGMENTS

The presented study was supported by the National Science Foundation (NSF) CMMI-CIS #0800858, NSF-REU #1041800 and #0944273, and SKANSKA USA Building, Inc., ThingMagic Inc., and Avery Dennison Corporation. Their support is gratefully acknowledged. Any opinions, findings, and conclusions or recommendations expressed are those of the authors and do not necessarily reflect the views of others.

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