PASSIVE RFID-BASED ASSET TRACKING AND PROJECT MANAGEMENT ON A LARGE HOSPITAL PROJECT

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ABSTRACT: *As construction job sites get larger and more complex, the need to increase building protocol control and safety is becoming more necessary. Having a real-time tracking system for materials, equipment and personnel of a job site will help project managers to enhance the safety, security, quality control, and worker logistics of a construction project. In this paper we will present the method of integrating Radio Frequency Identification (RFID) and Building Information Modeling (BIM) for real-time tracking of materials, equipment, and personnel. The purpose is to generate real-time data to monitor for safety, security, quality control, and worker logistics, and to produce leading indicators for safety and building protocol control. The concept of reference tags will be utilized along with a cloud server, mobile field devices, and software to assist the project managers with staying connected with the job site, from supply chain management to installation. Hardware components include RFID tags, portal RFID readers, fixed turn-style readers, and mobile handheld devices. The system was deployed on a 900 thousand square feet hospital project that consisted of three major buildings, 125 contractors, and 1,200 workers. Preliminary results show that the integration of these technologies enhances productivity, reduces scheduling issues, assists in subcontractor management, and provides real-time information on deployed crews and building activities. High-level metrics have been developed at the project and large contractor level. Additionally, the system also provided real-time information on local worker participation as part of the project goal. Based on experimental analysis, we demonstrate that the RFID and BIM system is a practical and resourceful tool to provide real-time information and location tracking to increase safety, security, and building protocol control.*

KEYWORDS: *Asset tracking, Building information modeling (BIM), Building protocol, Cloud Server, Human resources, Passive radio frequency identification (RFID), Project management, Quality control, Safety, Security, Worker Logistics.*

1. INTRODUCTION

Large scale projects require a productive and efficient workforce to stay on schedule and under budget. Maintaining high efficiency and productivity requires the constant monitoring the work force and project In particular, the status of labor forces is an important area to maintain for completing a project on schedule. A large percentage of construction costs result from the quantity of labor hours spent completing the desired tasks. Thus, by maximizing labor productivity, companies can avoid additional costs due to falling behind schedule. Many factors determine whether workers are able to complete their tasks at the necessary pace including experience, age, skill, motivation, and leadership. Appropriate work conditions can also influence the entire operation, such as project size and complexity, site accessibility, labor availability, equipment use, and local climate (Hendrickson 2009, Lee et al. 2008). In order to determine whether the construction process is operating at maximum efficiency or can be adjusted to improve its effectiveness, additional construction improvements can be identified in terms of productivity analysis of work crews, material transport, and the overall approach to a project. However, the monitoring and analysis of labor productivity has mostly been done manually, in which manual analysis have been shown to be time consuming, subjective to judgments and error prone (Ogelsby 1988, Allmon et al. 2000,

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Goodrum et al. 2006). Integrating technology to automate the monitoring and analyses is a way to reduce the human component and increase accuracy and reliability. Projects with higher automation and integration of information technology improved between 31% and 45% in productivity (Zhai et al. 2009).

The University of California San Francisco's (UCSF) Medical Center at Mission Bay is a large, 900 thousand square feet, hospital project that consists of three major buildings, 125 contractors, and roughly 1,200 workers. This public sector project has successfully implemented innovation project delivery models such as Target Value Design, lean construction principles, and Building Information Modeling (BIM). In addition to BIM, the project utilized an RFID-based building access protocol system that provides visibility of personnel and construction assets, including equipment and materials, on the jobsite, and helps the team plan work more efficiently. The use of this technology creates a more intelligent and automated job site, resulting in numerous benefits, such as improved safety and security, equipment protection, improved work quality, and more effective workforce. Importantly, the system allows for the monitoring and verification of protocols and ordinance, such as the San Francisco Office of Economic and Workforce Development (OEWD) mandatory local hiring ordinance (Office of Economic and Workforce Development 2011). The San Francisco OEWD mandates that certain government funded projects hire a percentage of local workers by trade. Although the UCSF hospital does not meet the criteria to follow the ordinance, it is voluntarily doing so to benefit the local community.

This paper highlights the collaboration of the team to apply lean construction principles and BIM within the contractual framework of the project. Additionally, the method of integrating Radio Frequency Identification (RFID) and BIM for real-time tracking of materials, equipment, and personnel is presented.

2. PROBLEM STATEMENT

Large scale projects with a large work force area are expected to contain issues with the sequencing of trades, the safety and security of the site, and quality control. Planning and sequencing of trades throughout this project could potentially be difficult as there will be more than 125 subcontractors, and over 800 workers on the site daily (peak hours will even have close to 1,000 employees on site). Consequently, it is extremely important to be able to monitor all personnel on site at any given time, especially during the interior build-out of the facility, since the trades (e.g. mechanical, electrical, and plumbing) will often be overlapping.

The safety and security of everyone on site, including workers and visitors, is the utmost importance on any jobsite, regardless of size. However, larger and more complex projects can be more challenging to maintain the highest level of safety and security. For instance, in the event of an emergency, an evacuation, or a lock down, being able to determine the exact number of workers and personnel on site will be critical, and the more people there are the bigger the challenge it is to have every single person accounted for. Manual recorded keeping of daily personnel and visitors could be potentially be inadequate, and would require a lot of time. Additionally, the monitoring of a large amount of personnel can be tedious and time consuming. On a traditional construction site, options addressing the challenges associated with safety and security are limited. Before, security would need to be placed at each entrance zone to verify the authorization and monitor the head count of workers entering. Even with personal ID badges, a security guard would have to write down who enters, thus limiting the amount of workers that can enter at a time and slowing down the flow of traffic.

Controlling access to hazardous zones of the jobsite is also important to verify only authorized and trained personnel can gain access. Having an untrained worker enter a hazardous area, such as a high voltage utility room, can lead to serious injury or death. Ensuring workers are properly trained before they are allowed to enter a more stringent building protocol project zone is important. However, it is difficult to monitor who has access to certain zones, even if some workers received proper training. Having a security guard or supervisor at each zone entrance is unfeasible and uneconomical.

Large construction projects also have problems with quality control and rework since there are many trades and workers around in the same area. In such situations, completed tasks by subcontractors are at risk of being damaged due to the amount of traffic through the area or the other subcontractors coming to do other work in the same location. Therefore, minimizing traffic in certain areas and understanding what area a subcontractor needs to be in can help limit rework. However, a supervisor that constantly monitors the workers to verify they do not walk through the wrong areas is not practical.

3. LITERATURE REVIEW

Real-time access to the locations of workers, materials, and equipment has been a significant advancement to the management of construction processes. There have been attempts to automate the analysis and tracking such as mobile tracking in lay down yards. Examples of these attempts include pre-cast concrete, fabricated steel elements, and automated tool tracking. Technology that has been researched to provide real time access include radio frequency identification (RFID) (Jaselskis 1995, Song et al 2006, Ergen et al. 2007, Grau et al. 2009, Costin et al. 2012), ultra wideband (UWB) (Teizer et al. 2007, Cheng et al. 2011, Yang et al. 2011), GPS (Oloufa et al. 2002, Pradhananga and Teizer 2012), and multiple sensors (Razavi and Haas 2010). RFID, UWB, and WLAN technology has been shown to be successful in a variety of applications including asset tracking, inventory management, on-site security upgrades, and productivity analysis (Goodrum et al. 2006, Rueppel and Stuebbe 2008, Li and Becerik-Gerber 2011, Cheng et al. 2011, Taneja et al. 2011). UWB can be implemented to track and determine the location of resources in a jobsite by utilizing multiple readers to identify the location of tags (Bohn and Teizer 2010, Cheng et al. 2011). However, UWB requires a careful installation of multiple readers at known locations and cannot be used when the tags are stationary and the reader is mobile. Additionally, RFID implementation in an outdoor environment led to a 4.2% increment in steel erection productivity (Grau et al. 2009).

3.1 Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) is a method of communication that uses radio waves. The system is composed of a tag, which is read by an RFID Tag reader, and a computer that receives the data from the reader. The tags can be active (battery powered), semi-passive or semi-active (battery-assisted), or passive (no battery). The transponder and transceiver (reader) gather and transmit the information to a RFID tag wirelessly, without necessarily needing to be in the direct line-of-sigh to the tags. First, the reader sends a radio frequency signal to the tag. The tag then sends the signal back to the reader along with any information or data that it may be storing, such as an identification number as each tag can have its own unique identification number. Upon receiving this data/information, the reader sends it to the computer where it is stored and analysed. The information sent to the computer includes items like the time at which the signal was received, which reader received it, and with what strength. The database in which the information is sent to can be utilized in many ways as the data can be linked to additional information that is stored on the tag. For example, a tag's unique identification number can be linked to further information held in a database that further describes that tag with items like a unit name, trade performed, manufacturer, etc. This information can be made easily accessible to users, such as a project manager, and can utilize queries help to increase productivity and efficiency throughout a project.

RFID technology is rapidly becoming more capable and complex, helping to track materials, workers, and equipment in real time as well as produce a visual of the locations and resources on a construction site. The use of RFID technology has been found to enhance the user's ability to locate materials that have been tracked by the RFID readers with an improvement ratio of 8:1 over manual tracking. The enhancement of this technology has led to testing of passive tags. These tests found that passive ultrahigh frequency (UHF) tags are durable enough to work in various harsh conditions, despite the existence of extreme moisture, pH, temperature, and pressure (Ross et al. 2009). This technology, compared to the limited bar code system that requires line of sight read range, provides significantly greater read-ranges and can be utilized in both outdoor and indoor conditions ranging in temperatures from −40 °C to 200 °C (Ross et al. 2009). Costin and Teizer (2012) also reported that the mobile RFID antenna devices as they are used in many commercial passive RFID applications comply with the Federal Communication Commission (FCC) and Industry Canada RF radiation exposure limits for the general population if a safe distance of humans to the antenna of 20 cm is kept. Though there are many benefits of passive RFID tags, there is a drawback in that there are no self-reporting capabilities. The read range typically is limited to up to ten meters, depending on the antenna type. So though this is significantly greater than a bar code system for example, there are still some limitations. The benefit of having a larger readability range, however, is that a single reader can be utilized to read multiple tags within this range (Costin et al. 2012). This capability is also limited in that environments exposed to either multipath or metal surfaces are at risk of experiencing signal attenuation due to the metal surfaces and the signal bouncing (Vogt and Teizer 2007).

RFID technology has been even further utilized by successfully pairing with Building Information Modelling (BIM) for supply chain management (Sawyer 2008). There are other technologies being researched, but they require the additional resources provided by the facility (Costin et al. 2012). Linking these two technologies will allow for tracking user-specified locations (e.g., at turnstiles or at gates) in real time and lead to more productivity and efficiency on a job site.

3.2 Building Information Modeling (BIM)

Integrated building technologies allow a convergence and integration of systems to play a greater role in overall building performance (Kean 2011). Building Information Modelling (BIM) helps to take the traditional building technologies a step further by adding more dimensions to the current 3D models. BIM pairs the geometric and parametric properties of a building's 3D model with all the information and properties of the building, such as information on the products, the site schedule sequencing, and owner histories (Eastman et al. 2008). With this technology, each component of the model can be viewed as well as its relationship with other objects in the model and the logical classification of objects in the model. All of this information is actually stored within the model. This is a very promising advancement in the Architecture, Engineering and Construction (AEC) industry as it creates an accurate, virtual digital model of a project (Eastman et al. 2008). BIM integrates all aspects of a project such as the structural, architectural, mechanical, electrical, plumbing (MEP), energy, etc. into the same platform, helping to lead to a better design through collaboration as well as optimizing performance. These benefits have led to a dramatic increase of the use of BIM over the years, in which 71% of construction companies, 70% of architects, and 74% of contractors are using BIM, and the use is expected to keep increasing (McGraw-Hill 2012).

Since this technology allows objects to hold their properties and are capable of parametric modeling, many manual techniques of tasks like estimating and scheduling have been replaced. BIM creates a platform that allows real time estimation and scheduling to occur based on the 3D model of the project created, both in the construction and operation phase. This changes the way a project has traditionally been categorized and how tasks are divided. The program has developed into a strong tool for project design and construction processes as it is continually receiving efforts to enhance its functionality and capabilities. Pragmatically speaking, BIM is a great tool as it looks at the whole project cycle, including the future of the project when it's in the operation phase. This is crucial as the design and construction phases of a project only constitute a small portion of the time and money that goes into the life cycle of a project. BIM helps to plan and estimate what the operation phase of the project will be like, and uses this throughout the design and construction phase.

4. EXPERIMENTAL ENGINEERING DESIGN

The purpose of this research is to utilize RFID-BIM integration to generate real-time data to produce leading indicators for safety and building protocol control. Additionally, the executed approach is to optimize cost and schedule while maintaining the scope, quality and performance. One of the many goals of the innovative project delivery models implemented on this site is to enhance quality control by reducing rework or damage of finished work.

The UCSF Medical Center team partnered with ThingMagic, Trimble's Radio-Frequency Identification (RFID) Division, and Georgia Tech in order to implement RFID-based tracking devices on the project and analyze the gathered data. These devices are a proposed solution to the sequencing, safety, security, and quality challenges previously mentioned. The RFID based building access will ensure more visibility and tracking of the equipment, materials, and personnel entering and exiting the jobsite while also allowing for the project team to increase work planning efficiency. RFID technology will present measures and data to help prevent these issues. The data analysis will allow for more efficient planning and work flow. This method of planning will help limit the amount of rework performed and limit access to zones where work has been completed, helping to limit damage. The entry security as well as asset and personnel tracking will help enhance the safety of the job site.

Approximately 80 RFID tag readers were installed in the infrastructure of the new building and multiple secure turnstiles with tag readers were places at the access points. The site was designated into different zones, each with a protocol level. The protocol level was based on the safety and security requirements, and authorized workers need specific training for each level to enter. All workers and visitors on site are issued a passive UHF-RFID-enabled identification badge to be read as the individual passes through the turnstiles or walks within the range of other sensors (see Figure 1).

There are two data types: the real-time data and stored data. The real-time data reports the current location when a tag is read, such as when an alert is sent for an unauthorized worker. All the real-time data is then reported to a cloud-based web portal where real-time email notifications and reports can be delivered daily. In addition to this reporting, a web service has been created in order to provide external software clients access to the data. This is done so the data can be analyzed and visualized in 3D. For example, Tekla BIM software with a custom plug-in will allow the users to filter the data to zoom in on the relevant data of the building section, time span, people, or assets desired (see Figure 2). Managers can now monitor the flow of people in and out of different zones, allowing for an instant email alert to be sent when an employee enters an unauthorized zone. These real time updates will be crucial in the event of an emergency as it will provide authorities will be able to determine who has been left in the building and where.

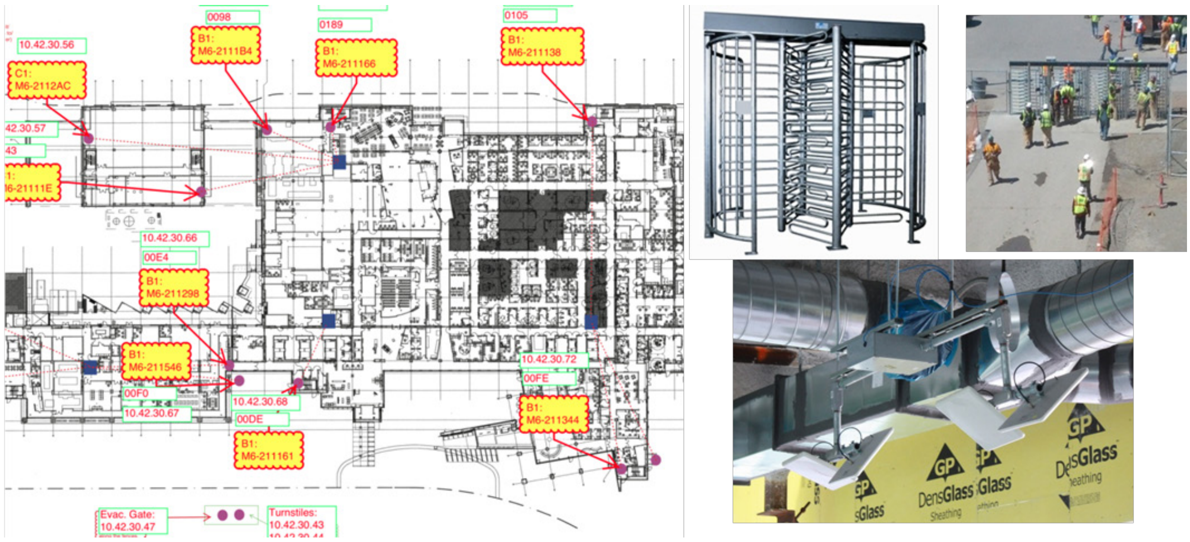


Fig. 1: Map of zones, turn-style readers, site entrance and fixed passive RFID reader and antennas.

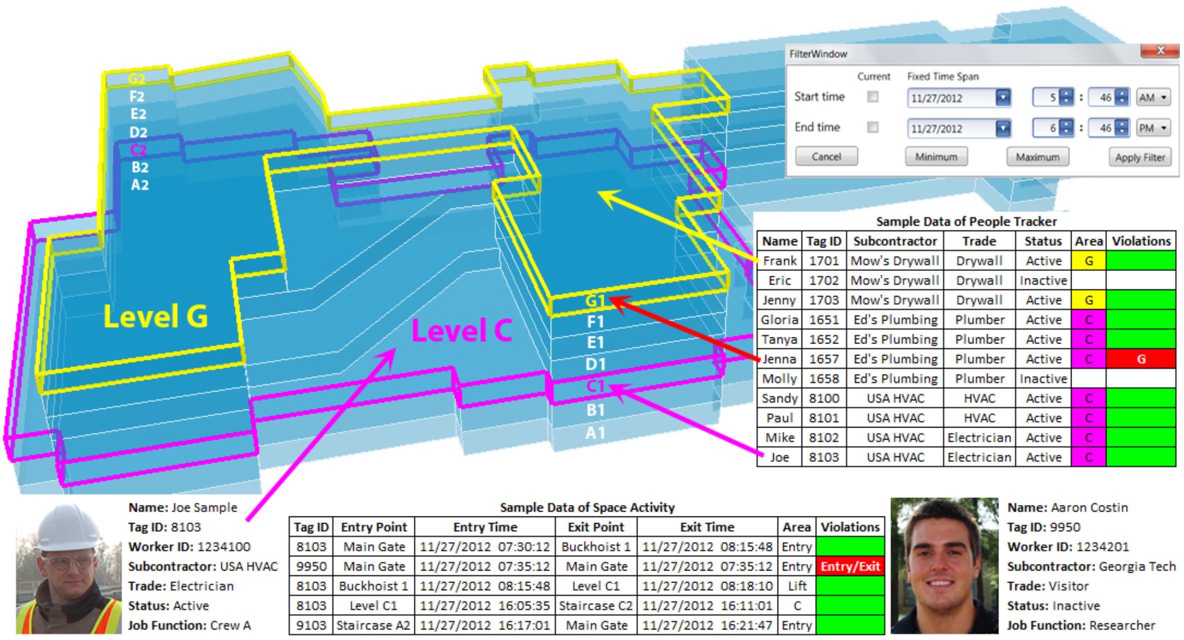


Fig. 2: Georgia Tech's software plug-in with workers and sample data of workers' locations in a BIM model.

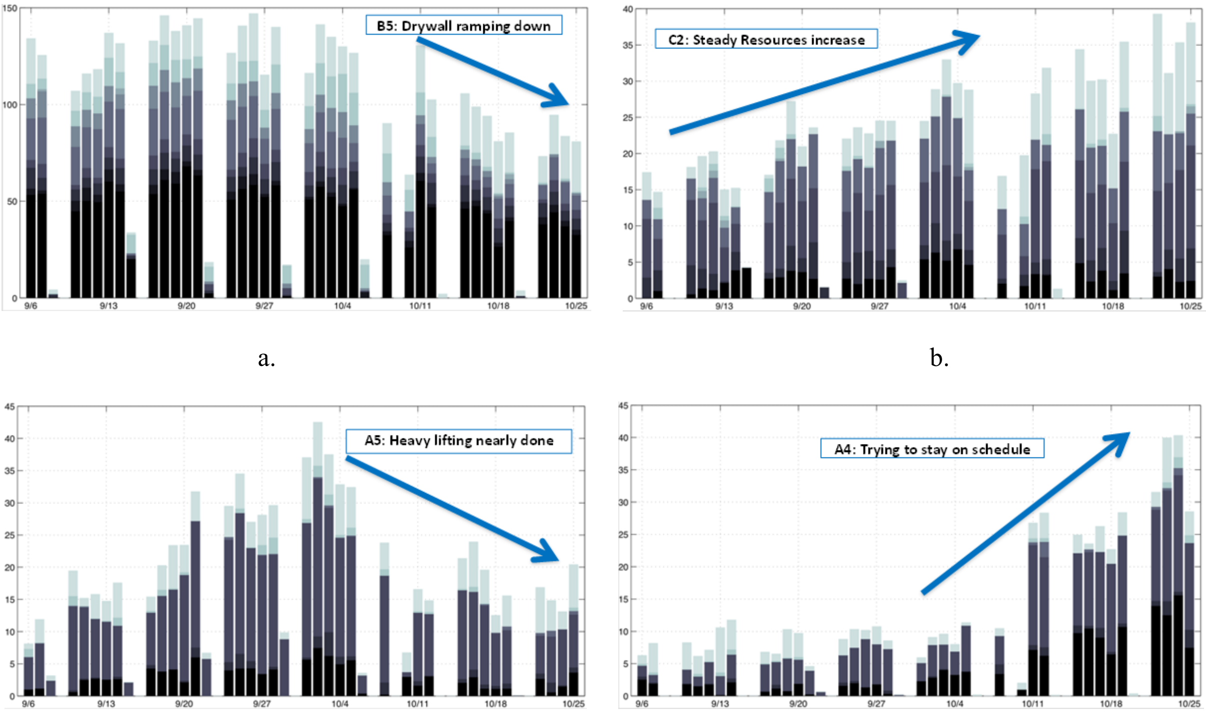
The modeling began at 25% design phase, thus ensuring that subcontractors were able to report their constructability inputs into the permit drawings. Superintendents also worked with the modelers in order to create a model that accurately portrays the means and methods of the planned construction as well as provide the details specific to the project conditions that may become part of the permit documents. This collaboration ensures that the project is in compliance with all the necessary permit documents and requirements. The structural models created are directly used to create the fabrication and installation drawings. By doing this, it will guarantee that everything installed meets the design requirements while satisfying the required permitting documents. The design models will also feed into Total Station units for an accurate site layout and installation. Many benefits come from creating a highly detailed model, such as the validation of the design, user requirements, and constructability as well as benefits in cost-savings, more reliable scheduling and increased field productivity. The time and effort put into creating these highly coordinated models results in higher predictability for schedule, material, and labor, leading to cost savings for the owners as the contingency budget can be lowered. These models allow for the modeling of detailed architectural, structural, and MEPF systems, including hangers and seismic bracing, drywall framing, concrete, rebar, exterior skin and site utilities. The detail can go as far to show drywall models including "critical" framing, such as corners, doors, and MEP opening framing, as well as the infill framing for crowded rooms such as patient rooms, ICUs, and operating rooms.

5. OPERATING RESULTS

In addition to the real time data the system produced, the stored data was filtered and analyzed for various aspects. The data can be graphed to compare the work in the different zones. Activities such as productivity, number of workers, and scheduling can be visualized to see the trends, progress, or even compare whether the work is on schedule. Having the data in visual form is important to for planning and coordinating future work. Importantly, knowing the current status and productivity rate allows for a more accurate assessment of what is needed. For instance, Figures 3a and 3b show the work is becoming to completion, and therefore not many workers are needed. Also, Figures 3b and 3c show the increase in number of workers to maintain the current schedule.

Verifying the compliance to local, state, or federal regulations is another important feature this system provides. For example, The San Francisco OEWD mandates that certain government funded projects hire a percentage of local workers by trade. Although the UCSF hospital does not meet the criteria to follow the ordinance, it is voluntarily doing so to benefit the local community. The goal is to have a mandatory participation level of 25% of all project hours within each trade to be performed by local residents. Each employee's information, including their trade and zip code, will be placed in a data base that is linked to their identification number. This new RFID technology will be able to track all employees by their given identification number, thus providing the resources to obtain an accurate assessment of the amount of employees with the local residential zip code. With this information, USCF has been able to accurately report the number of local residents on the site and the amount of hours they have performed in their trade. As seen in Figure 4, the UCSF Medical Center successfully met their goal to reach 25% local resident employees, and is working on achieving a 35% rate in 2014.

The system records all safety and security violations, which is important for record keeping and the production of leading indicators for safety and building protocols. When a worker enters an unauthorized zone, an alert is sent to the project manager notifying him of the breach. In addition, each breach is kept in a log, which can then be analyzed to fix the problem. For instance, if an unauthorized worker enters in by mistake, he will learn to not go in there without proper training. Additionally, a log will notify what workers still need to be trained to enter that zone. Examples of the log of violations for a specific area and duration are shown in Figure 2 as well. These violations were created by a visitor and a worker. It is important they had special authorization to enter the zone.



a. b. c. d.

Fig. 3: Full-time equivalent workers per day per contractor for work areas (a) B5, (b) C2, (c) A5, and (d) A4.

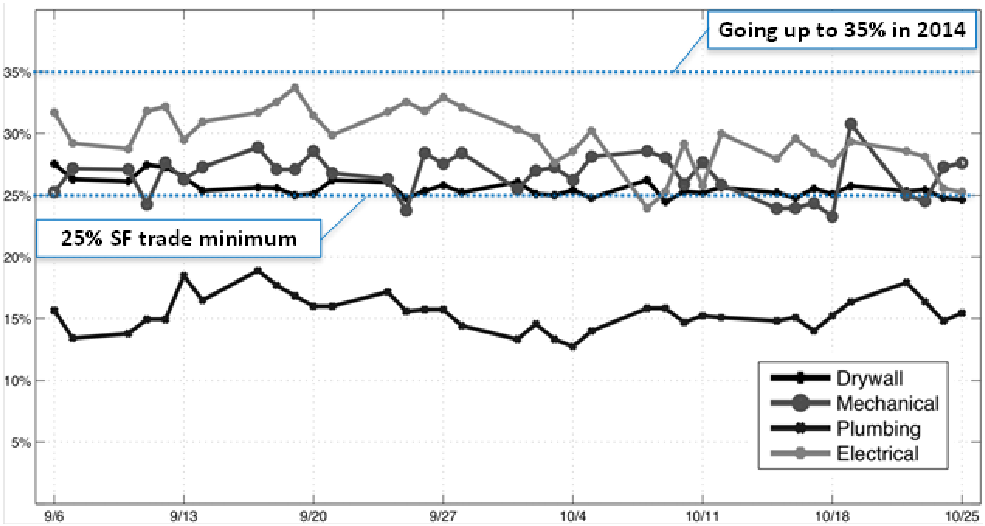


Fig. 4: Percentage of San Fransisco-based workers by subcontractor (Monday through Friday).

6. DISCUSSION AND CONCLUSIONS

RFID tracking technology applied on construction assets creates a more systematic, automated, and intelligent job site and results in benefits to both the project team and the UCSF Medical Center. The developed hardware system and data mining algorithms are able to detect personnel and assets as far as three to five meters away from the reader antenna, which is unlike the current, conventional manual access control. With this kind of range, workers will no longer have to swipe a badge at each sensor as they will be able to simply pass through check points and portals. Long range readers reduce the numbers of readers need to be installed, which is important on a large, congested site such as a hospital.

The following benefits and limitations were identified

6.1 Improved Security

Providing an accurate headcount has made it easier to ensure the safety of everyone, which is important on this large, newly developed, urban site that the hospital is being developed on. Crews are now easier to find and convey important messages to. Being able to locate the crews could be the difference in life or death in an emergency situation. The new technology allows for the assurance that only badged, authorized employees are entering the site and the zones that they are authorized for, which increases safety and lowers risks in those zones that may contain expensive equipment and materials. No longer will there need to be a hired security guard or supervisor just to monitor the work force in the various sections of the building. The use of this technology eliminates the need for these personnel and thus lowers costs.

6.2 Equipment Protection

Since this is a state of the art facility being constructed, there is a significant amount of expensive medical equipment to be installed. The new RFID system allows for all assets and equipment to be securely tracked and located at all times. This prevents the equipment from being lost or missing, which could potentially be a negative impact on the project's cost and schedule.

6.3 Improved Quality

Rework and damage to completed work are very realistic threats to the quality of the project. Foot traffic over completed work can cause damage to these finished projects and without proper monitoring and planning, rework is possible. Minimizing this traffic and ensuring that subcontractors are only in locations where they are necessary will help to limit damage and rework. A way to do this is to control and monitor access to the site and to ensure that workers are properly trained before they can enter the different project zones. With RFID technology, the project team is able to do this and is better able to monitor the progress of the different work zones, helping to better protect the finished work.

6.4 More Effective Workforce

As labor is almost half of a project's construction cost, it is imperative to improve the worker logistics on a job site. The RFID technology helps make this happen. With the data presented by the new technology, subcontractors are able to more efficiently plan their work, helping to meet project needs and identify variances. The data provides an understanding of how many workers are present on site daily and where majority of the work is being performed. This helps the subcontractors determine the appropriate amount of workers to deploy, preventing over- or under- staffing the project. The owner's dollars are being efficiently spent when the right people and skill sets are in the right place at the right time, and this comes from the improved work flow created. The real time data analysis during each work day is drastically different and more efficient than in the past when construction managers and owners used to have to wait for weeks or months to get the data analysis of how efficiently the workforce is performing, thus wasting money. The new system also provides the ability to measure travel times between work zones, with this information an adjustment can be made in material placement or path of travel, thus enhancing productive worker time.

6.5 Cultural Factors

Initially, subcontractors and workers showed concern that the system monitored their exact location at all times, however, through seminars and training, it was conveyed that the purpose of the system is to identify the zones where the worker was last seen, not determine their exact location at all times. Communicating this to the workers allowed them to feel more comfortable and see the benefits of the RFID system. Benefits such as enhancing the security of the project, only allowing authorized personnel onto the site, or ensuring that individuals without the proper training do not enter the wrong zones gave the workers a higher sense of security and assured the subcontractors that costly errors can be avoided.

6.6 Current Limitations

Although the benefits seem to outweigh its limitations, some warrant further investigation, for example: in building construction dynamically changing floor may require RFID hardware to be frequently relocated, few data mining algorithms exist that currently take not full advantage of the data that is gathered, people issues such as the perception of being tracked, legal issues of who owns the data and for what purposes it is used.

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