LEVERAGING RADIO FREQUENCY IDENTIFICATION TECHNOLOGY FOR PRODUCTIVITY ANALYSIS IN HIGH-RISE CONSTRUCTION

A Thesis
Presented to
The Academic Faculty

By

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In Partial Fulfillment
Of the Requirements for the Degree
Masters of Science in Civil Engineering
Georgia Institute of Technology

Georgia Institute of Technology
April 2010

LEVERAGING RADIO FREQUENCY IDENTIFICATION TECHNOLOGY FOR PRODUCTIVITY ANALYSIS IN HIGH-RISE CONSTRUCTION

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ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Jochen Teizer, for the opportunity to complete my Masters of Civil Engineering degree at Georgia Tech. His guidance and expertise provided me with the ability to conduct this research. I would like to thank my family and friends who have supported my research efforts over the past year. Thanks to all my lab partners who have given me assistance throughout my research efforts – Kangkui Wu, Matt Williams, Manu Venugopal, Tao Cheng, and Aaron Costin. Thanks to my committee members Dr. Ioannis Brilakis and Dr. Daniel Castro for their assistance as well as Dr. Kangari for his helpful advice throughout my graduate school career. Thanks to Andy Udell for his help in building the devices for my research. Thanks to Skanska USA Building, Inc. for its contribution in providing access to the construction site to measure the productivity of the material hoists and overall glass replacement process. Thanks to Harmon for allowing me to track their construction personnel to measure labor productivity. Lastly, I would like to thank those of whom contributed to this research but I have forgotten to mention.

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SUMMARY

Until recent developments, labor productivity had been analyzed manually requiring time-consuming work and the possibility of human error. Past research has shown the multitude of benefits obtained from implementing radio frequency identification technology within various construction sites including asset tracking, inventory management, and on-site security upgrades. 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. This paper presents the results of implementing radio-frequency identification technology and provides a study of labor productivity analysis for a window replacement project on a high-rise construction site. This extensive study tracks 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 work in both an indoor and outdoor environment simultaneously with a data recording software and database. The in-house development of the database allows for timely information retrieval of various items of interest in this study and requires less

The 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.

CHAPTER 1: INTRODUCTION

1.1 Problem Statement and Research Objectives

The construction industry relies heavily on maintaining the work schedule drawn out during the planning phase of the project. Companies aim to maximize the amount of capital received for a project by minimizing excess costs related to completing a project behind schedule. Unavoidable factors such as weather delays or equipment malfunctions generally play a role in delaying progress and must be overcome through weekend labor hours or larger work crews to make up for lost time. Past RFID research shows that common reasons for labor delays include the time lost locating missing materials on-site and inefficiencies in material and worker transportation due to the layout of the site. The task of manually locating and relaying information regarding a material, and transferring it on-site loses valuable work time. This paper intends to present additional factors relating to productivity and the benefits of incorporating radio frequency identification (RFID) technology within a commercial high-rise construction site. Conclusions regarding the productivity and overall effectiveness of the construction process are drawn from data gathered using RFID technology.

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.

1.2 Research Approach

In order to improve the labor productivity of a high-rise construction project with the use of an exterior material hoist, radio-frequency identification technology will be implemented in specific locations within the site. Workers, lifts, material transport carts, and windows will be tagged with unique passive RFID tags and tracked in real-time by strategically placed RFID readers. 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.

1.3 Significance of Research

While tower cranes are viable options in high-rise construction projects due to their capacity to transport heavy loads of materials, site layouts and safety concerns may make them risky and inefficient for certain projects. In this window replacement project at the Westin Peachtree, the multiple buck hoist system was chosen by Skanska for worker and material transport throughout the 73 story building. RFID technology will be used to acquire data regarding the timestamps of the workers, each individual buck hoist, transportation carts, and windows to determine whether this technology can be utilized for labor productivity purposes. Placing passive RFID tags on the windows and carts during the construction process will show the location of the item with the exact time it arrived to that location. Studying the time it takes to complete various tasks that make up an operation are important for revealing the advantages and disadvantages of work procedures and produce insight into productivity. Past research by a team from the Construction Industry Institute (CII) led by Dr. David Grau included a study to determine whether technology really has an impact on construction labor productivity and to what extent. Their research concluded that projects with higher automation and integration of information technology improved between 31% to 45% in productivity. Furthermore, in material tracking studies, the use of RFID allowed laborers to locate materials with an improvement ratio of 8 to 1 over manually tracking. Overall, CII's research found that RFID implementation in an outdoor environment led to a 4.2% increment in steel erection productivity. 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.

1.4 Site Overview

The Westin Peachtree Plaza is located in downtown Atlanta, Georgia creating a confined layout of the site for construction purposes. The building consists of 73 stories creating the need for a material and worker transport system that extends from the street-level to the 73rd floor. However, due to an enlarged diameter of the building from the street level to the 16th floor, the building was divided into two main areas for research: the 16th floor platform level and any sections of five floors located above the platform level. A lack of storage space at the base of the building makes it necessary to store roughly 84 pieces of glass in the hallways of the desired installation floor.

Figure 1.1: Aerial View of the Westin (Image from Skanska)

CHAPTER 2: BACKGROUND/LITERATURE REVIEW

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 Westin is having all 6,350 windows replaced by Skanska USA Building along with Arnold & Associates and Harmon Glass within 15 months. 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 buck hoists have been placed at the street elevation which then rise to the 16th floor platform where a second set of additional buck hoists are located. This set of lifts is able to carry people and equipment to the 73rd floor.

Figure 2.1: Elevator Lifts Used for Window Replacement

The four buck hoists employed on the exterior of the building are designed by the Alimak Hek Group in order to provide the entire construction process with a means to transport workers and materials throughout the high-rise. These hoists have a payload capacity of over 4,000 pounds and transport large materials with complete accessibility to each floor of the building. However, the height of a building in construction largely affects the efficiency of lifting equipment installed on-site thus affecting the overall schedule of the project (Lee et al. 2008). The Westin hotel consists of 73 stories in height raises concern over maintaining tight work schedules. Therefore advanced and efficient lifts must be chosen for installation on the exterior of the building.

2.1 Methods of Lifting and Hoisting in High-Rise Construction

The tower crane is a commonly used mechanism that is available to the construction industry for high rise construction is the tower crane. With roots tracing back to the Roman Empire, cranes are easily identified on a construction site. In developing countries like China and the United Arab Emirates, tower cranes appear to compose the skyline and are commonly used on large scale vertical construction. Anchored by bolts to large concrete pads, this freestanding massive piece of equipment can safely reach a height of around 260 feet, or around 22 stories. However, when securely attached to the side or top of a structure, a tower crane can be used on practically any building of any height. 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. Also, the contractor should plan on devoting a large portion of the surrounding area to being designated as restricted areas for safety as well as laydown areas for materials. 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. 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.

The robotic tower crane is a new technology developed by Lee et al. (2009) is expected to produce advantages in construction scheduling, labor and material costs, and improvement in safety. By using a series of laser devices, GPS, an encoder, an accelerometer, and other devices, researchers expect a robotic tower crane to improve productivity between 10%-50%. 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.

2.2 Current Labor Productivity Practices

Gathering data for on-site productivity studies can influence the planning and execution of a project in terms of schedule, necessary labor crew size, and material deliveries. Before the use automated tracking systems such as RFID, manual data collection was used for productivity purposes with a stopwatch being incorporated for recorded time studies. Khoury (2009) discusses the current need for site engineers, inspectors, and other site personnel to spend excess amounts of time to manually search through and organize data, documents, and drawings to access task-related information. According to Oglesby, several limitations of this method exist including the decision-making of the observer to decide instantly the point in time to start and stop time cycles. This is an issue in construction as many activities occur irregularly and cycles are not clearly defined. Another concern is that data may vary significantly in studies with larger work forces or great amounts of materials.

Past research has been conducted on potential tracking technologies with the intent of showing a person or material's position and in an indoor environment. Khoury et. al (2009) conducted experiments and compared the benefits of Wireless Local Area Networks (WLAN), Ultra-Wide Band (UWB), and Indoor GPS. Khoury explains that WLAN-based tracking systems prove to be economical with a simple equipment deployment task of placing access points in a desired area. However, calibration is necessary by taking sample points at a variety of locations which can be a strenuous task for relatively poor accuracy in terms of identifying the location of an object. Meanwhile, UWB and Indoor GPS provide high precision locations but possess several drawbacks as well. UWB and Indoor GPS both as requiring line-of-sight between the receiver and transmitter or reference tag, respectively, and require considerable time for deployment. Although these technologies can locate and track items in an indoor setting, none are able to record the timestamps which is vital for productivity analysis purposes.

2.3 Safety and its Impact on Productivity

Safety has become an increasingly important focus for construction companies as they strive for avoiding jobsite accidents. The emotional toll placed on family, friends, and co-workers along with the costs associated to the injuries and negative effects on labor productivity have made zero-tolerance a common policy for companies. Many sites expose workers to high elevations in which fall hazards become an important issue. One common hazard involves the use of lifts and cranes to transport workers or materials to various floors of a building. The Center to Protect Workers' Rights (CPWR) performed a study using data from 1992-1998 of fatal falls in construction and found that 152 deaths were related to elevator use. In terms of material transport, tower cranes are often used for large construction projects. The 2009 CPWR report displays statistics that the average number of deaths involving cranes was at 42 that year, an increase from the average of 22 deaths found in 2008. Statistics recorded by the U.S. Bureau of Labor Statistics show that from 1992-1999, 100 out of 339 deaths occurred from tip-over or collapses of personnel lifts such as cranes and boom-supported lifts. While there was an overall decline in construction deaths in 2008, the number of total crane-related fatalities increased by 37% and as well as a 42% increase to crane deaths located on a construction site (Ichniowski 2009). According to OSHA, crane safety failures include side loading of the boom, impact loading of the boom, inadequate leveling of the crane, and recoil. OSHA states that 33% of crane accidents are related to operator error, 31% due to support failure, and 22% to the lack of proper outriggers. Furthermore, CPWR noted that cranes pose a danger to the surrounding public. In the case of the Westin jobsite, the placement of a crane for material movement would certainly pose a hazard to the nearby public below. Although the productivity of a crane may surpass that of a hoist system with its ability to greater loads at one time, the benefit of choosing a buck hoist system for transport is the decrease in physical strain placed on workers. With cranes, workers are needed to load and unload the heavy material to the hook of the crane causing them to apply excess strain on their bodies. Perttula et al. (2006) concluded that vertical transportation of materials by elevator decreases physical loading while also improving upon accident risk when compared to the other method. The decrease in physical attrition also maintains a worker's normal productivity level as little time is needed to recover throughout the long day. The use of a cart for horizontal transport further improves upon the health of the worker. Oglesby (1988) states the evidence is strong that attention to worker fatigue and overall health can improve worker productivity while also reducing the potential for injury. Human error is decreased as well with the use of an elevator as certified buck hoist operators are present to carry out the task of employing the lift system. Meanwhile, crane operators are given the difficult task of transporting large loads with precision despite the existence of dangerous factors such as wind. While a buck hoist may restrict the pace of transporting materials, its use in a high-rise construction setting enables workers to maintain their productivity by allowing them to avoid the constant physical toil spent when using a crane.

2.4 RFID Technology Background

Radio frequency identification (RFID) systems, classified as active or passive, are an emerging technology 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 items. This wireless technology uses the antenna to emit radio signals through the transceiver which begins communication between it and the transponder. The unique data from the tag is then received and transferred back to the transceiver in order to attain the data and a computer system then processes the information for 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. In addition, RFID tags are able to read multiple tags simultaneously and uniquely recognize facility items, store information regarding maintenance history of these items, and continuously update the information in real-time (Ergen 2007).

Passive RFID systems, or read-only tags, account for a less expensive technology related to RFID. The benefits of these tags derive from a reduced cost as passive tags receive their power from the transceiver eliminating the need for an onboard battery. Thus passive tags are exceptionally small in size and have an infinite operational life as long as the reader is powered to send radio waves to the tag (Ross 2009).

Figure 2.2: Passive RFID tag

The cost is inexpensive at roughly $0.20 apiece as the 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 nearly 4 m (Goodrum 2006). However, performance is reduced in close proximity to any metal surface as the metal causes signal attenuation (Tajima 2007).

Active RFID systems are read-write tags that possess an internal battery providing it with considerably greater read ranges of up to 100 m in free air (Wang 2008). Another benefit of active tags includes their ability to support large data storage capacities of 32 to 128 kilobytes that can be constantly changed or updated and allows it to accumulate history with the ability of self-reporting. Although active tags prove to have many benefits, they are limited by operational life of the battery found to last up to 10 years and are considerably larger in size than passive tags (Ergen 2007). Currently the cost of active tags may reach as much as $20 apiece; however, the price is estimated to decrease over time (Tajima 2007).

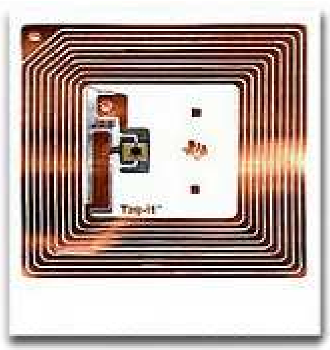


Figure 2.3: Active RFID tag with Battery

Despite the higher cost, Goodrum et al. (2006) concluded that active RFID has the potential as an asset tracking technology to improve tool inventory and allocation on construction sites as well.

RFID technology can be further classified into low, high, ultrahigh, or microwave frequency tags depending on the intensity of the radio waves used to transfer information. Tajima (2007) compared the different types of tags and found that low frequency tags are passive with a relatively high cost but are the best choice when working near metals or wet surfaces. High frequency tags have a lower cost than low frequency tags and work well when reading near metals or wet surfaces. Ergen et al. (2007) tested active UHF tags and found that tags located underneath the ceiling and moderately surrounded by metal produced a reading range half of the original distance. A tag surrounded by high amounts of metal and partially blocked by a wall had a reading distance 20-25% of the original distance. Ultra high and microwave frequency tags are found both as active and passive tags and have a faster data transfer rate than low and high frequency tags. However, ultra high tags are inferior in their ability to read near metal and wet surfaces but are the cheapest type of tag. Meanwhile, microwave tags are the least effective when reading near metals and wet surfaces and are the most expensive.

In terms of labor productivity benefits, Goodrum et al. (2005) has shown that RFID has the capacity to ensure that the necessary supply of tools is available to crews throughout the jobsite or facility. Thus, time spent searching for missing tools can be saved while through manual tracking, the location of the cart would be unknown until discovered by a worker. The time lost in this instance would lead to a delay in the overall replacement schedule of the windows. Furthermore, Grau et al. (2006) performed field tests which found that the labor time spent on tracking each unique component in a lay down yard decreased by a ratio of 8 to 1 while the number of items not immediately located reduced by a proportion of 18 to 1. Additional benefits of RFID implementation is its potential to reduce the size of work crews and overall project schedule days, reduce the number of work schedule interruptions, improve worker safety and productivity by ensuring proper maintenance of equipment, and improve cash flow through Just in Time Inventory Management techniques. Based on these results it is evident that RFID can significantly improve the pace of the construction process.

2.5 Shortcomings of Past RFID Research

Past research has shown various benefits of implementing radio frequency technology in an outdoor construction setting. RFID has been used to track materials within an outdoor job site, locate buried assets for maintenance purposes, and reduce project activity times. However, research has yet to prove that the application of RFID can successfully work within an indoor setting consisting of wide-ranging elevations. In terms of material hoist productivity, the author was unable to find research regarding the analysis of material lift systems regarding productivity or material movement within the Journal of ASCE or Automation in Construction, among other notable journals.

CHAPTER 3: METHODOLOGY

3.1 Data Collection Process

The automated tracking of assets on a construction job site can be implemented by using radio frequency based technology. This form of technology involves the utilization of passive radio frequency identification tags and active broadcasting radio antennas. The RFID tags use induction to produce unique identifications that can be attributed to individual assets on site.

The first step in implementing the RFID tracking system on the Skanska job site was to issue each worker, loading cart, window, and buck hoist a unique RFID tag. Each construction worker was issued two unique RFID tags. One RFID tag is placed on the front of their construction safety helmet while the other tag is placed on the inside of the safety helmet. Each tag is given a different ID number in order to help maximize detection, allow data collection to record whether any tag was unable to be read, and to compare the signal strength between the two tag locations for future project considerations.

Figure 3.1 Passive Tag Placement on Worker Hardhats

Each RFID tag contains sixteen bits of information that is used to differentiate each asset; for example: workers will have tag IDs in the following format: - 100000000000000XiYi where X and Y are variables that are placeholders for each unique tag.

Additionally, each buck hoist has eight RFID tags attached to its entry doors. Four tags are 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 is destined for replacement on the Westin arrives at the construction site in large wood-framed batches, and is separated into groups of six. Each batch is tagged with a single RFID tag, and all the batches have the same tag ID number, but are unique to the floor at which they will be installed.

Furthermore, the setup of the tracking technology consists of strategically placing six of the radio frequency readers, and two mobile laptop computers. The actual glass replacement process and work zone consists of five floors at a time. Actual work takes place on the middle three floors while the outer two floors are used primarily as buffer zones to control construction noise that may affect guests staying at the Westin.

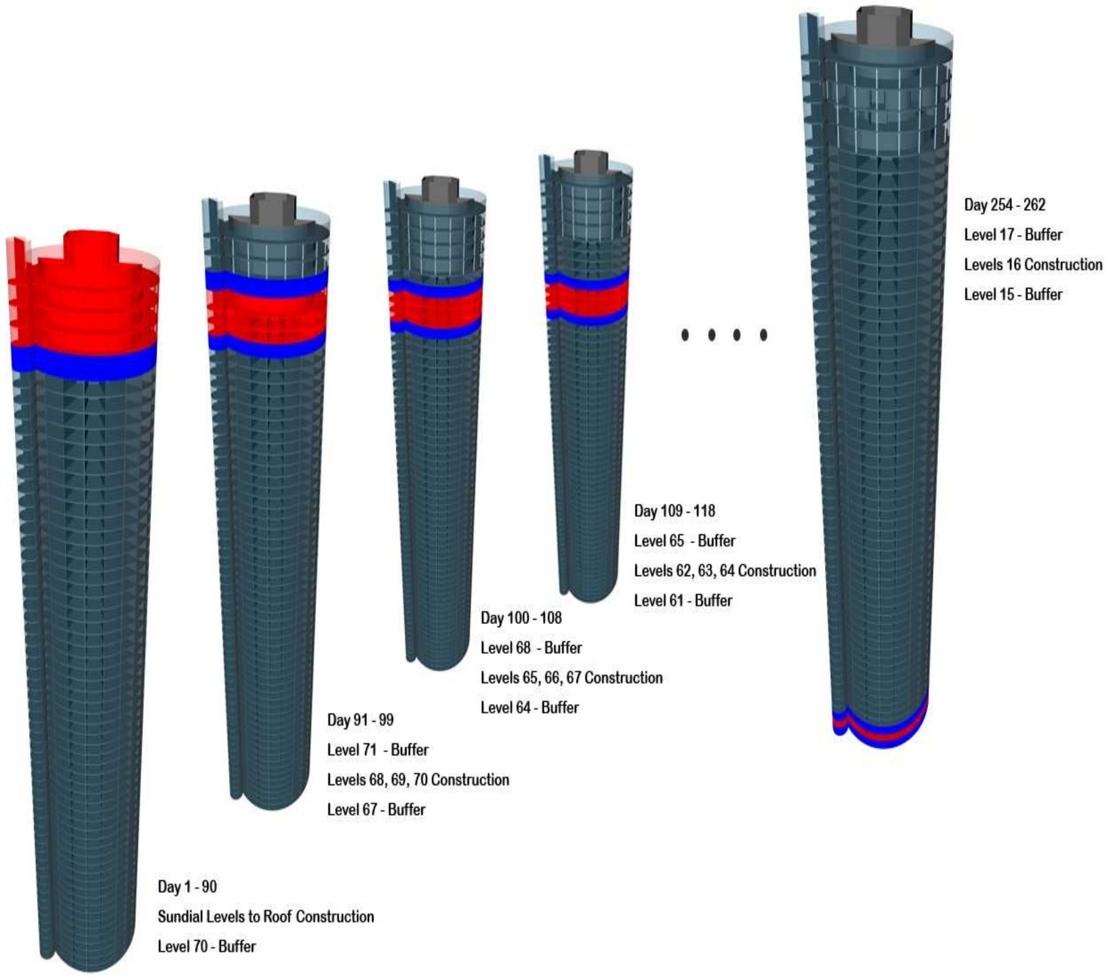


Figure 3.2 Tower Work Sequence and Buffer Zones

One reader is placed on each of the three work floors and faces the entrance of the buck hoist. Each antenna reader has a particular IP address that is used for identification and allows the database to display locations. The antenna readers are connected wirelessly via a Wireless Local Area Network (WLAN) through an onsite router, then to the laptop computer that is used to store the collected data. The wireless routers on site have enough signal strength to penetrate between five floors. The same connection methodology is implemented on the sixteenth floor of the hotel. The primary reason for deploying two separate systems is because it is impossible for a single router to broadcast a signal from the sixteenth floor to the top floors; with a maximum separation of fifty floors. There are two readers located on the platform of the sixteenth floor with auxiliary add-on antenna extensions. These add-ons are used to increase the range and visibility of each of the readers that they are 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 was to successfully connect the antenna readers with the laptop computers. Each laptop computer has installed software that was developed in the RAPIDS laboratory at Georgia Institute of Technology. The software allows the acquisition of data that consists of:

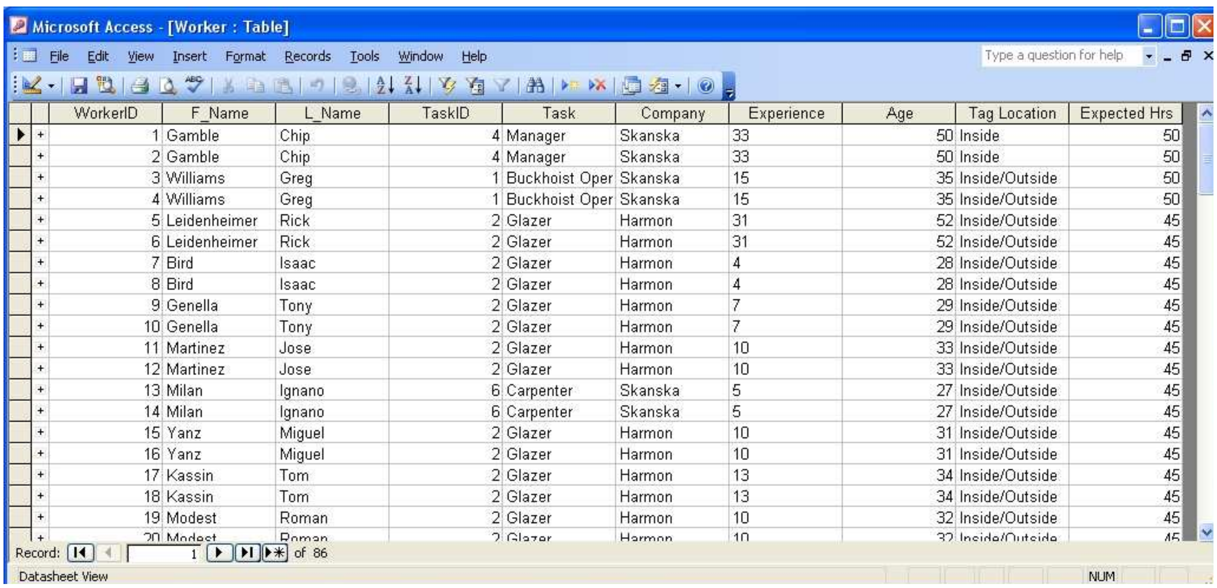
- RFID tag ID
- Read frequencies
- Time of read
- Signal strength and Link Quality Indicator
- Antenna Reader I.P.

The wireless router will be powered on first so that it would be allowed to broadcast DHCP wireless network. Next, each antenna reader will be powered on. The antenna readers are preprogrammed to recognize the broadcasted signal of the specific router that is responsible for the wireless network. However, in a larger network or if multiple wireless networks are present within the construction site, each reader can be reprogrammed to only connect with a particular wireless router. After the readers are powered on, they will go through a boot sequence, and if they are successful in connecting to the wireless router, a green light emitting diode on the bottom of the antenna readers will light up. If there is no signal or if the latency of the signal is too high, a red light will come on instead; indicating a failure to connect, and the signal of the wireless router must either be enhanced, or the location of the router must be changed. Once the antenna readers are connected, the laptop computer will attempt to connect to each reader individually through the router and the installed software. There is no limit to the number of readers that can be connected simultaneously to the laptop in the wireless network.

The fourth and final step is to begin the data collection. For the purpose of this research, data collected over a two week period, from February 22 – March 5 is used. Despite the relatively short collection period, the sample data is sufficient for analysis as it covers multiple floors of construction in a project with repeat, routine procedures being performed on each floor. Recorded data will be stored as either an undesignated file type or text file format. Readings from the antenna readers will occur at variable intervals that can be changed by the user to fit the type of data they desire. The default read rate of the readers is set to 100Hz.

3.2 Data Analysis Tool

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 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 simply choose specific desired 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. These four categories were given separate tables storing useful information. For example, Figure 3.3 shows a portion of the table that was created for the workers involved in the Westin window replacement project.



WorkerID	F_Name	L_Name	TaskID	Task	Company	Experience	Age	Tag Location	Expected Hrs
1	Gamble	Chip	4	Manager	Skanska	33	50	Inside	50
2	Gamble	Chip	4	Manager	Skanska	33	50	Inside	50
3	Williams	Greg	1	Buckhoist Oper	Skanska	15	35	Inside/Outside	50
4	Williams	Greg	1	Buckhoist Oper	Skanska	15	35	Inside/Outside	50
5	Leidenheimer	Rick	2	Glazer	Harmon	31	52	Inside/Outside	45
6	Leidenheimer	Rick	2	Glazer	Harmon	31	52	Inside/Outside	45
7	Bird	Isaac	2	Glazer	Harmon	4	28	Inside/Outside	45
8	Bird	Isaac	2	Glazer	Harmon	4	28	Inside/Outside	45
9	Genella	Tony	2	Glazer	Harmon	7	29	Inside/Outside	45
10	Genella	Tony	2	Glazer	Harmon	7	29	Inside/Outside	45
11	Martinez	Jose	2	Glazer	Harmon	10	33	Inside/Outside	45
12	Martinez	Jose	2	Glazer	Harmon	10	33	Inside/Outside	45
13	Milan	Ignano	6	Carpenter	Skanska	5	27	Inside/Outside	45
14	Milan	Ignano	6	Carpenter	Skanska	5	27	Inside/Outside	45
15	Yanz	Miguel	2	Glazer	Harmon	10	31	Inside/Outside	45
16	Yanz	Miguel	2	Glazer	Harmon	10	31	Inside/Outside	45
17	Kassin	Tom	2	Glazer	Harmon	13	34	Inside/Outside	45
18	Kassin	Tom	2	Glazer	Harmon	13	34	Inside/Outside	45
19	Modest	Roman	2	Glazer	Harmon	10	32	Inside/Outside	45
20	Modest	Roman	2	Glazer	Harmon	10	32	Inside/Outside	45

Figure 3.3 Table Storing Worker-Related Information

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. In this project, the data that was collected by the RFID technology was saved in text format by date and therefore saved into tables by date as shown in Figure 3.4.

2010-02-22-Floor 62 : Table

Tag ID	Timestamp	Signal Strength	Reader ID
120000000000002291f9	01:00:01	70	192.168.1.55 #3
10000000000000045afb	01:00:02	79	192.168.1.55 #3
10000000000000032a1c	01:00:02	76	192.168.1.55 #3
120000000000000814d1	01:00:02	80	192.168.1.55 #3
120000000000002291f9	01:00:03	76	192.168.1.55 #3
1200000000000021a19a	01:00:03	66	192.168.1.55 #3
10000000000000045afb	01:00:04	77	192.168.1.55 #3
10000000000000032a1c	01:00:04	74	192.168.1.55 #3
1200000000000021a19a	01:00:04	68	192.168.1.55 #3
120000000000002291f9	01:00:04	71	192.168.1.55 #3
120000000000000814d1	01:00:04	85	192.168.1.55 #3
120000000000000814d1	01:00:05	60	192.168.1.2 #1
1200000000000050cf2c	01:00:05	97	192.168.1.52 #2
10000000000000302c2c	01:00:05	88	192.168.1.52 #2
1000000000000011186f	01:00:05	75	192.168.1.2 #1
120000000000002291f9	01:00:05	71	192.168.1.55 #3
1200000000000021a19a	01:00:06	70	192.168.1.55 #3
10000000000000045afb	01:00:07	80	192.168.1.55 #3
10000000000000302c2c	01:00:07	85	192.168.1.52 #2
120000000000000814d1	01:00:07	81	192.168.1.55 #3

Record: 1 of 14995

Figure 3.4 Table Showing Data for February 22, 2010

By creating relationships between the various tables, one can retrieve specific information about a worker or cart rather than simply viewing Tag ID's. A form was created with the database to provide users with the option of viewing certain data sets. Figure 3.5 displays the database menu which allows one to search specific information related to the tracking of carts, glass, lifts, and workers by their specific Tag ID's or by date.

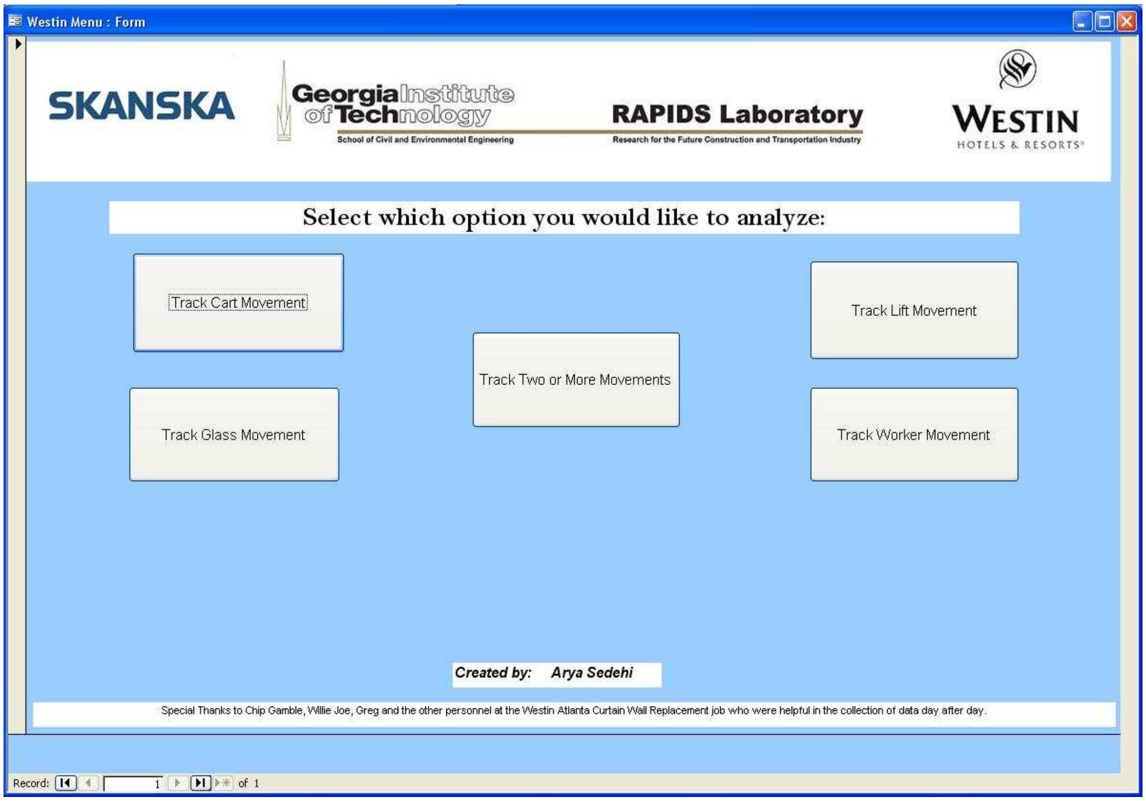


Figure 3.5 Westin Menu for the Database

For example, by choosing the "Track Worker Movement" button, one is taken to new screen where data can be found by date, by individual, or with both sets of information as seen in Figure 3.6. Pressing "Run Query" with only a date chosen will display all worker related information for that specific date while selecting a worker along with a specific date will produce a table of relevant information to that particular day. The results of selecting the date "2010-02-25" along with "Williams, Greg" for worker produces the results displayed in Figure 3.7.

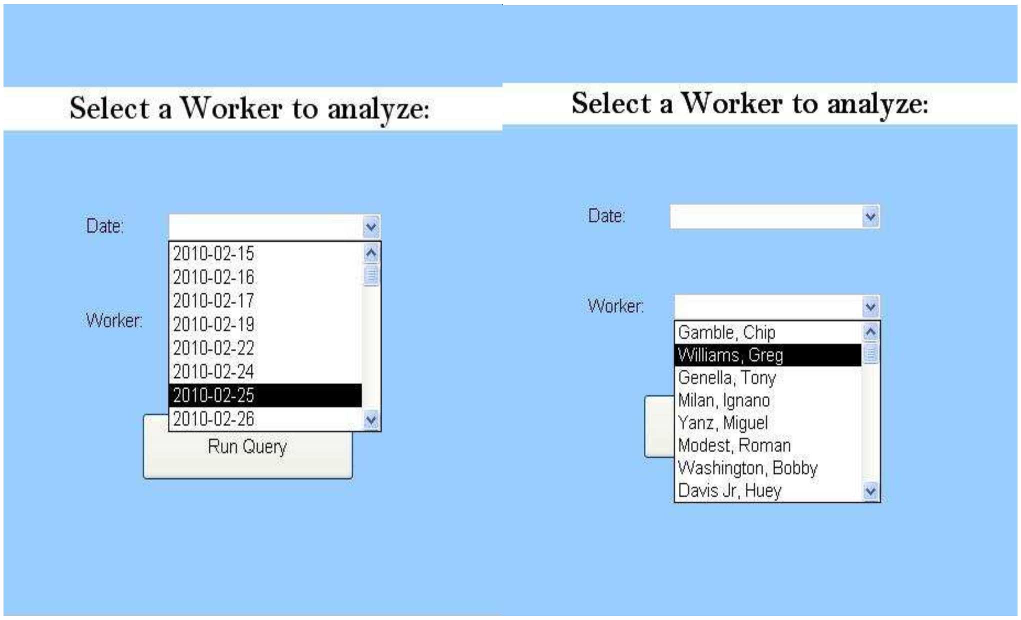
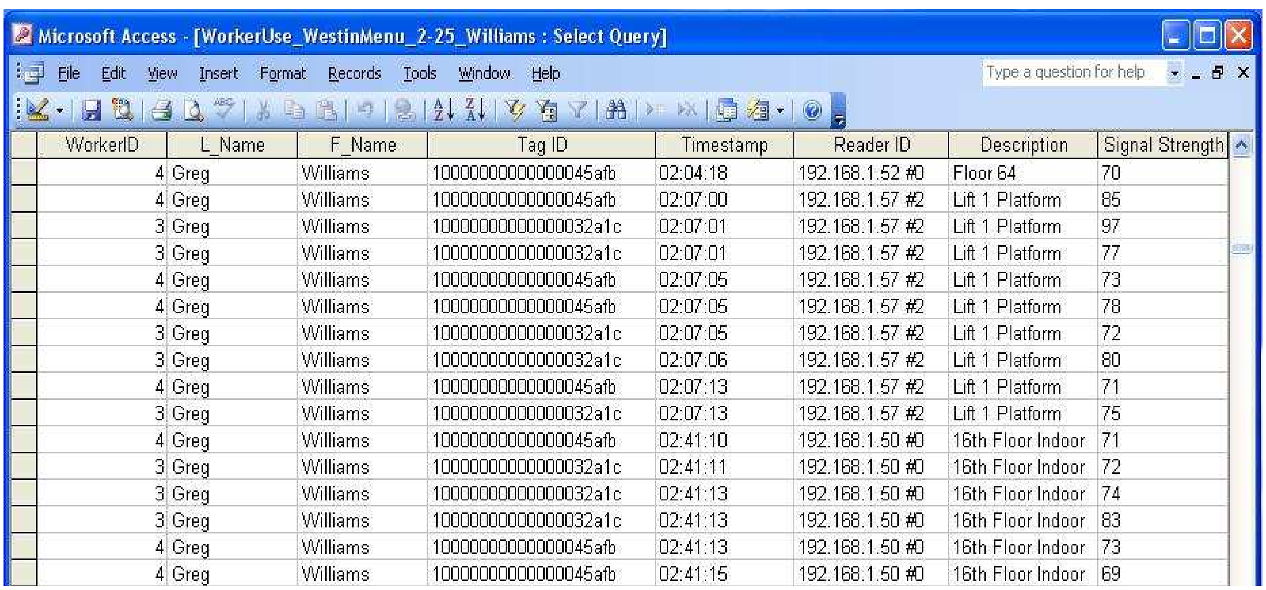


Figure 3.6 Date and Worker Options for Analysis

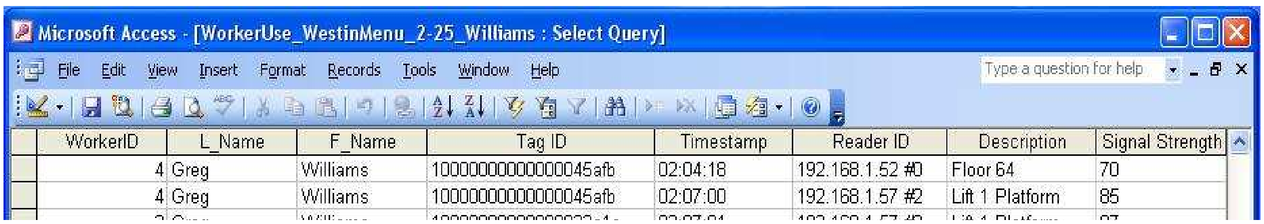

Microsoft Access - [WorkerUse_WestinMenu_2-25_Williams : Select Query]

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 3.7 February 25th Data Results for Greg Williams

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 for creating a tool for analysis 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.



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

Figure 3.8 Results of Worker Travel Times between Locations

Data can be filtered to extract data such as the amount of time it takes a worker to reach various locations from different starting points. Figure 3.8 displays two consecutive tag readings for Greg Williams where he left the 64th floor at 2:04:18 pm and arrived at the 16th Floor Platform at 2:07:00 pm. These two timestamps can be used to find the travel time for this distance which is calculated to be 2 minutes 42 seconds in this instance. 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.

Microsoft Access - [WorkerUse_WestinMenu_2-25_Williams : Select Query]

WorkerID	L_Name	F_Name	Tag ID	Timestamp	Reader ID	Description	Signal Strength
3	Greg	Williams	100000000000000032a1c	01:57:32	192.168.1.50 #0	16th Floor Indoor	74
4	Greg	Williams	100000000000000045afb	01:57:43	192.168.1.57 #2	Lift 1 Platform	68
3	Greg	Williams	100000000000000032a1c	01:57:45	192.168.1.57 #2	Lift 1 Platform	66
3	Greg	Williams	100000000000000032a1c	01:57:53	192.168.1.57 #2	Lift 1 Platform	76
4	Greg	Williams	100000000000000045afb	01:57:54	192.168.1.57 #2	Lift 1 Platform	77
4	Greg	Williams	100000000000000045afb	01:57:57	192.168.1.57 #2	Lift 1 Platform	77
3	Greg	Williams	100000000000000032a1c	01:57:57	192.168.1.57 #2	Lift 1 Platform	70
3	Greg	Williams	100000000000000032a1c	01:58:07	192.168.1.57 #2	Lift 1 Platform	71
4	Greg	Williams	100000000000000045afb	01:58:08	192.168.1.57 #2	Lift 1 Platform	77
3	Greg	Williams	100000000000000032a1c	01:58:12	192.168.1.57 #2	Lift 1 Platform	77
4	Greg	Williams	100000000000000045afb	01:58:12	192.168.1.57 #2	Lift 1 Platform	75
3	Greg	Williams	100000000000000032a1c	01:58:19	192.168.1.57 #2	Lift 1 Platform	75
4	Greg	Williams	100000000000000045afb	01:58:19	192.168.1.57 #2	Lift 1 Platform	72
3	Greg	Williams	100000000000000032a1c	01:58:22	192.168.1.57 #2	Lift 1 Platform	73
4	Greg	Williams	100000000000000045afb	01:58:22	192.168.1.57 #2	Lift 1 Platform	74
4	Greg	Williams	100000000000000045afb	01:58:22	192.168.1.57 #2	Lift 1 Platform	73
3	Greg	Williams	100000000000000032a1c	01:58:40	192.168.1.57 #2	Lift 1 Platform	72
3	Greg	Williams	100000000000000032a1c	01:58:49	192.168.1.57 #2	Lift 1 Platform	72
3	Greg	Williams	100000000000000032a1c	01:58:59	192.168.1.57 #2	Lift 1 Platform	69
4	Greg	Williams	100000000000000045afb	01:59:00	192.168.1.57 #2	Lift 1 Platform	76
4	Greg	Williams	100000000000000045afb	02:04:00	192.168.1.52 #0	Floor 58	72

Record: 384 of 4250

Datasheet View NUM

Figure 3.9 Worker Wait Time Analysis of RFID Collected Data

Figure 3.9 depicts the scenario utilized by the analysis tool for productivity measurements. In this case, the worker walked out of the 16th Entry Room at 1:57:32 pm and waited on the platform for 1 min 17 seconds before leaving the platform at 1:59:00. The worker then arrives at his desired location, Floor 58, at 2:04:00 which calculates that this particular occasion took the worker 7 minutes 17 seconds to reach his desired location from the time he entered the lift platform. 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.

CHAPTER 4: EXPERIMENTS & RESULTS

4.1 Technology Used

The data collection system that was employed uses passive RFID technology and includes a reader, an antenna, and a passive RFID tag. The readers, which are elevated close to the ceiling, send out a signal from the antenna and then identify the tags that are placed on the hard hats of the workers or on materials and lifts. The signal strength diminishes as the tags distance to the reader increases or is hampered by concrete or metal interference. In order to run three readers on separate floors, a router was incorporated to improve the signal reception of the readers and antennas and provide a wireless network connection for the computer software. A laptop computer was set-up both on the platform on floor 16 as well as on the upper floors for data collection and reader connection. Figure 4.1 shows the reader used in the outdoor platform environment which has been attached within a plastic tub to protect it from weather elements such as rain, snow, or wind while Figure 4.2 shows a reader and antenna placed in an indoor environment.

Figure 4.1 Outdoor Reader for Platform with Protective Plastic Cover

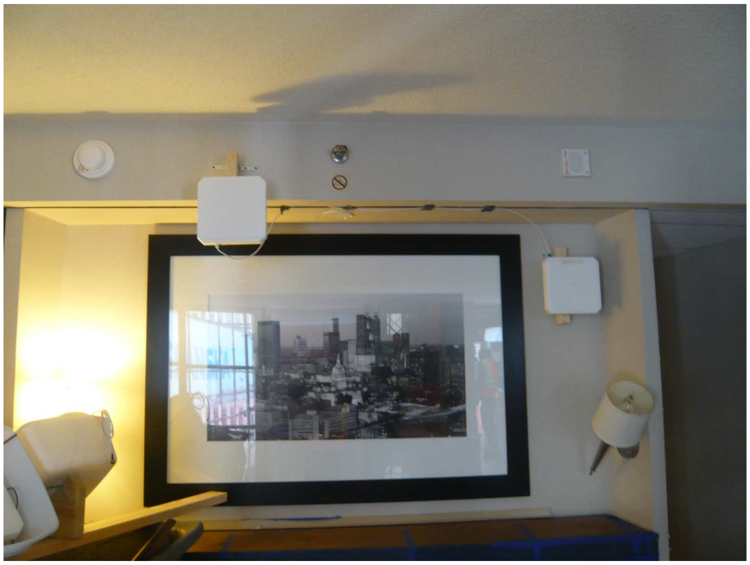


Figure 4.2 Indoor Reader and Antenna Set-up

The two readers shown above are connected in order to enhance the performance and minimize the amount of error in the data collection process while recording data under a shared reader identification to display the correct floor location information during data analysis. Figure 4.3 shows a passive tag with adhesive on one side enabling it to be placed on any object. Due to signal interference that occurs from the tag's location on a metal surface, a buffer of foam was needed to exist between the RFID tag and the metal surface.

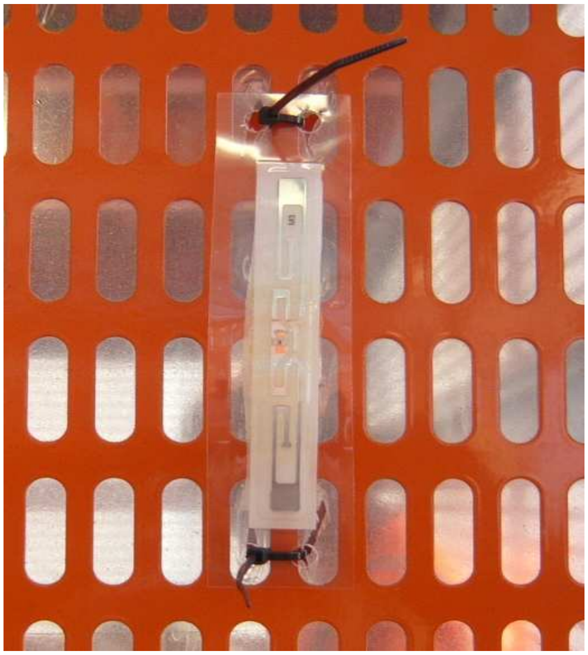


Figure 4.3 Passive Tag Placed on Lift Cage

Due to the lift's placement on the exterior of the building, the tags were laminated in order to protect them from poor weather conditions such as rain or snow. The laminate was chosen as it does not interfere with the radio frequency technology.

Microsoft Visual Basic 2005 was incorporated to run the source code created to collect the data recorded by the readers. The software was linked to the readers and recorded important information such as the tag's unique identification, the time that the signal was received, the signal strength between the tag and the reader, and the reader identification into a text file.

	Tag ID	Timestamp	Signal Strength	Reader ID
	2000000000000063c65	01:00:06	75	192.168.1.57 #1
	12000000000002291f9	01:00:06	69	192.168.1.57 #1
	1000000000000032a1c	01:00:06	68	192.168.1.57 #1
	1000000000000045afb	01:00:06	78	192.168.1.57 #1
	120000000000021a19a	01:00:06	69	192.168.1.57 #1
	900000000000022e3de	01:00:06	75	192.168.1.57 #1
	12000000000002291f9	01:00:06	81	192.168.1.57 #1
	1000000000000045afb	01:00:21	71	192.168.1.57 #1
	2000000000000063c65	01:00:21	75	192.168.1.57 #1
	900000000000022e3de	01:00:21	81	192.168.1.57 #1
	1000000000000032a1c	01:00:22	67	192.168.1.57 #1
	120000000000021a19a	01:00:22	70	192.168.1.57 #1
	12000000000002291f9	01:00:22	71	192.168.1.57 #1
	1000000000000045afb	01:00:22	76	192.168.1.57 #1
	2000000000000063c65	01:00:22	70	192.168.1.57 #1

Figure 4.4 Data Recorded by Visual Basic 2005

4.2 Installation of RFID Technology

Based on the site's layout within a high-rise building, the data collection was focused on two main areas. The 16th floor needed one system of readers, antennas, a router, and laptop while another system was needed for three floors undergoing window replacement tasks on upper floors of the building. Using a combination of screws, wood, twist ties, and power tools, the objects were safely installed in the necessary locations. A reader, antenna, and laptop were placed in the platform entry room as seen in Figure 4.3. In order to overcome the signal interference from the highly dense metallic hoist platform, a reader and an antenna were needed in front of both sets of lifts as displayed in Figure 4.5.

Figure 4.5 Reader and Antenna Placed on Buck Hoist Platform

The readers needed to be elevated to a height which would not interfere with workers or materials; therefore, they were connected to a horizontal 2x4 which was secured to the scaffolding. Plastic tubs were placed around the readers to protect them from water damage with an additional plastic cover wrapped around the entire system to ensure protection. The readers and tubs were angled at 45 degrees facing downward to increase the read in order to maximize the likelihood of recording tag data.

The installation of the readers in the three upper floors posed less problems as metal was not present to hinder the RFID technology. The readers were connected to a small piece of 2x4 using an L-bracket while another L-bracket would connect these pieces to the wall. These readers were specifically placed across from the buck hoist entry doors to ensure that the tags on the lift would be read.

Figure 4.6 Reader Installed Across from Material Hoist on Floor 63

Figures 4.7 and 4.8 show the placement of the readers within the platform and upper floor layouts, respectively.

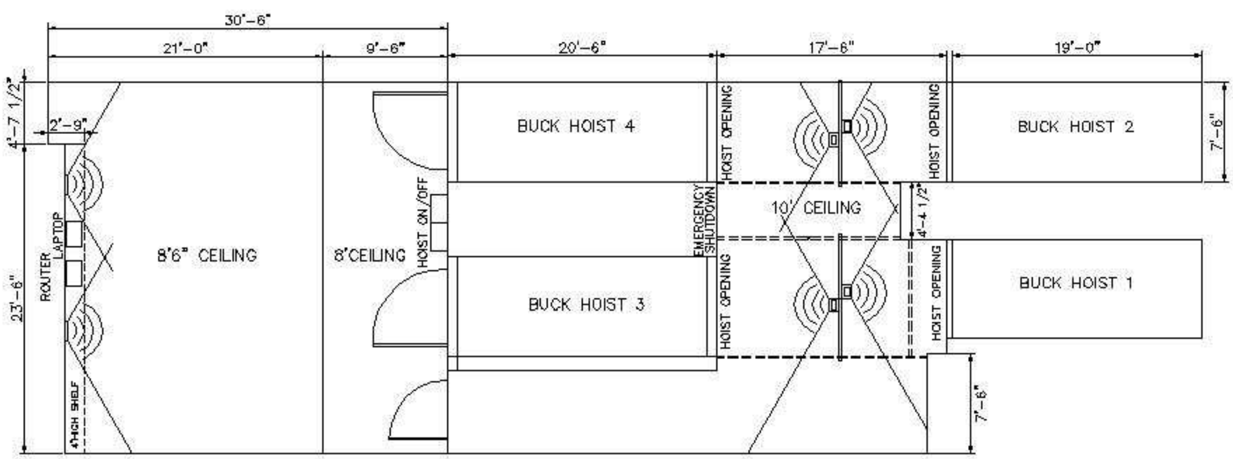


Figure 4.7 Reader Locations on the 16th Floor Platform

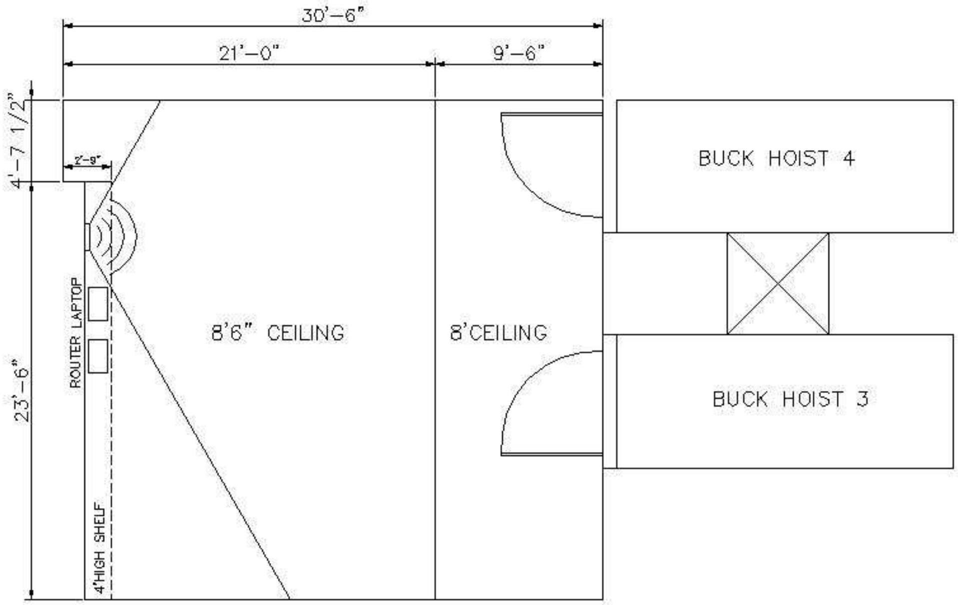


Figure 4.8 Reader Placement on the Upper Floors

Based on these pre-planned locations, any worker, material, cart, or lift would be tracked from the moment the unique tag reached the desired elevation. Also, these areas were determined to be the most commonly accessed areas as workers commonly use the lifts to access different floors of the high-rise building.

4.3 Results of Labor Productivity Analysis

4.3.1 Manual Calculation of Blind Spots

The labor productivity of this project was greatly influenced by the confined layout of the site as the rate at which glass can be transferred from the delivery truck to the desired floor depends on the availability of the hoists. As mentioned previously, there are only two lifts that reach from the street level where the glass is removed from the delivery truck to the platform on the 16th floor where the additional two hoists are located to transport the glass to the desired floor. With only two hoist operators available on-site, only one batch of glass can be transported from the street to the platform where it can then be placed onto the other hoist to travel the remaining height of the building. In terms of productivity, this process appears slow as work only progresses when Lift 1 and 3 return from the higher elevations. While a batch of glass is being taken up to its desired location, the next batch of glass is removed from the truck using a gantry system that is only able to move one batch at a time.

Figure 4.9 Glass Removal from Delivery Truck

Multiple workers are needed to safely place each batch of glass onto the hoist deck for transport preparation as seen in Figure 4.10. Due to space limitations, workers are able to move only one batch onto the deck at a time as they must wait for the buck hoist to transport a batch and return before the next batch can be placed onto the loading deck. The shortest duration of time for removing a single set from the truck and placing it on the deck took nine minutes. Additional time is lost as at least 2 workers are needed to safely remove the glass from the protective wood frame and place it onto a cart for transfer.

Figure 4.10 Glass from Delivery Truck Placed onto Cart for Transport

Although the delivery of glass only occurs every three or four days, the entire process of moving each batch of glass from the street to its destination takes roughly three hours to accomplish. On average, each shipment of glass arrives at 10 am and does not reach the upper floors until 1 pm causing delays throughout the work schedule. This is a time-extensive process as each delivery consists of 12 batches of glass. Since two of the hoists are occupied for the glass transfer, workers are often forced to use the service elevators within the interior of the Westin to move throughout the building as two of the lifts are occupied. Workdays excluding the need to transfer glass show an increase in productivity as lifts were often available for use upon a worker’s arrival at the lift. Two days of data regarding the total use of the buck hoists were recorded and averaged into the graphs shown in Figures 4.11 and 4.12. Figure 4.11 gives an hourly break down the number of times each lift was operated to show the amount of activity over the course of a workday. It is clear that the peak times of lift use occurs from 8:00 am to 10:00 am and again from 1:00 to 2:00 pm. This type of information can be utilized to plan work tasks during less active lift operations to avoid unnecessary wait delays. The results of the lift operations are somewhat misguiding as a total of sixteen of the operations were put into effect by the hoist operator traveling unaccompanied by additional workers. The cause of unaccompanied lift operations was the need for the operators to search manually for workers needing pick-up since only a select few workers were given radios for communication.

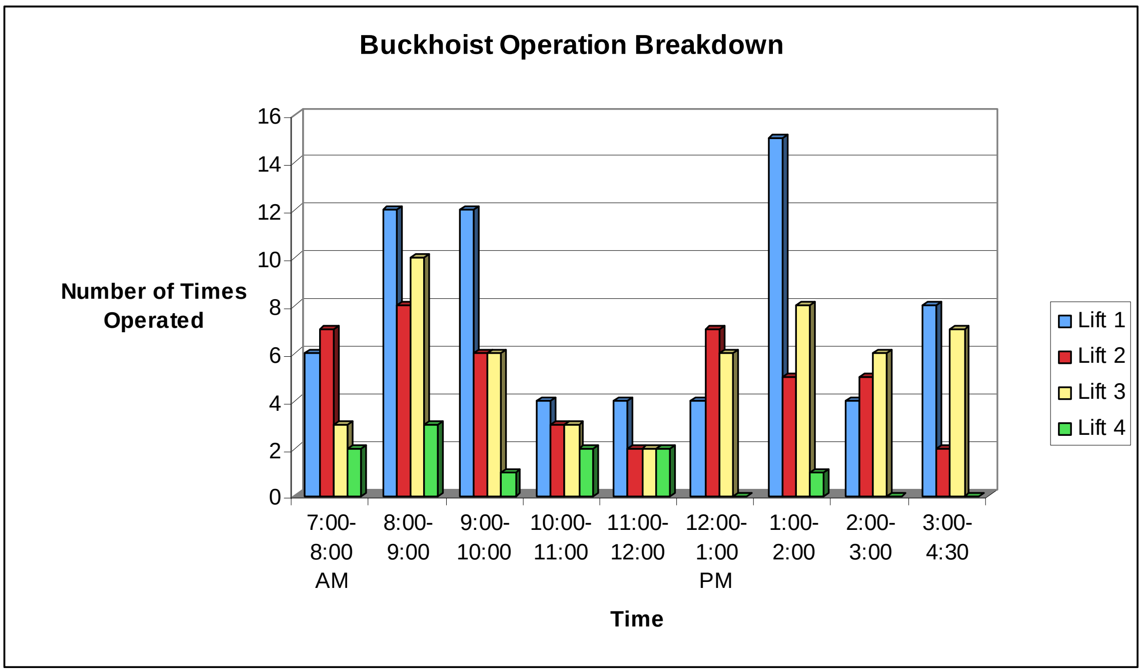


Figure 4.11: Hourly Hoist Operation Analysis

Figure 4.12 shows that Lifts 1 and 2 were used most often possibly due to the need for workers to reach the street level; the entry location to the site with a small amount of space set aside for two large trash dumpsters holding glass, wood, and other trash.

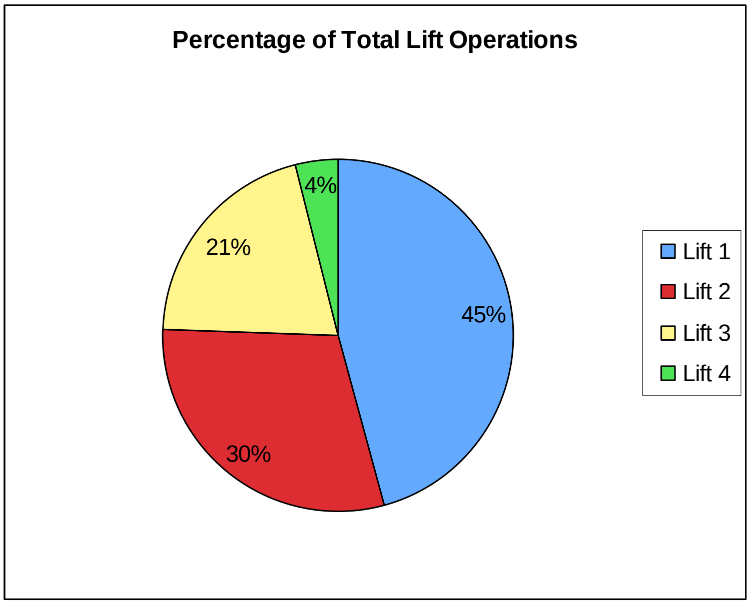


Figure 4.12: Break down of Total Lift Use

It is important to note that Skanska employs two buck hoist operators while two of Harmon's employees are licensed to operate the hoists as well. It was clear from observing operations and speaking to the employees that Lifts 2 and 4 are often reserved for use by Harmon employees while Lifts 1 and 3 are operated by Skanska whenever needed. This explains the greater use of Lifts 1 and 3 in comparison to their respective areas. The average number of workers that traveled by way of the lifts throughout the days is shown as well. This information can be useful in terms of making lifts more available during certain hours of the workday. Rather than limiting Skanska's use of Lift 2 and 4 throughout the day, it can be seen from the analysis that Lift 4 may be utilized by any certified operator after 12 pm as it was in use by only one individual after 12 pm.

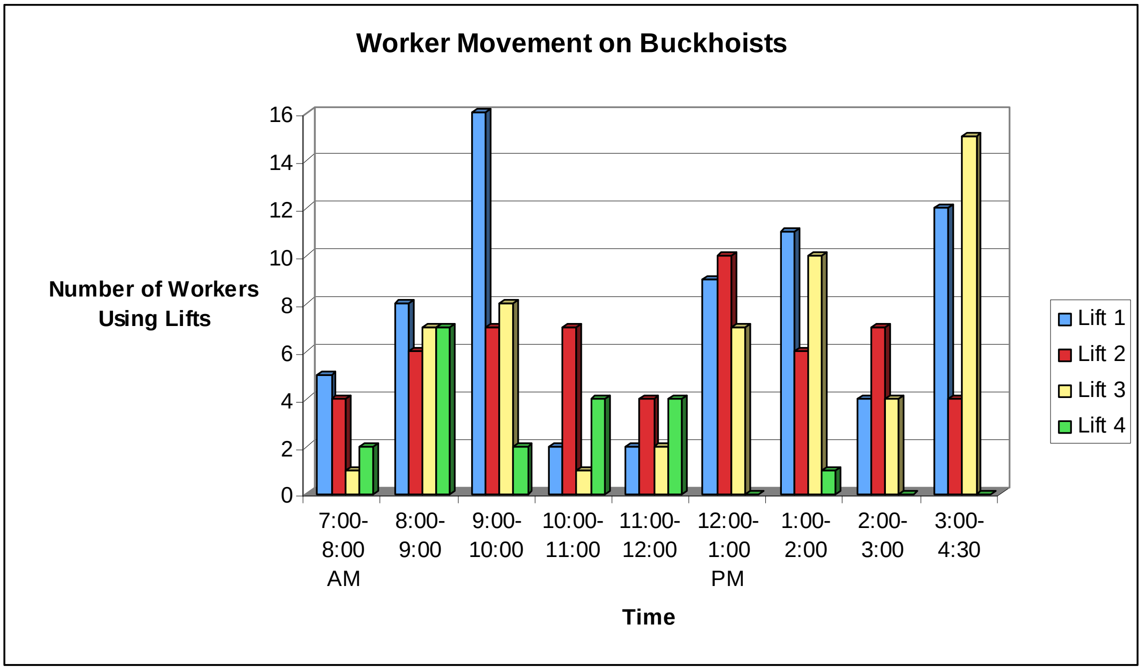


Figure 4.13: Hourly Worker Movement on Lifts

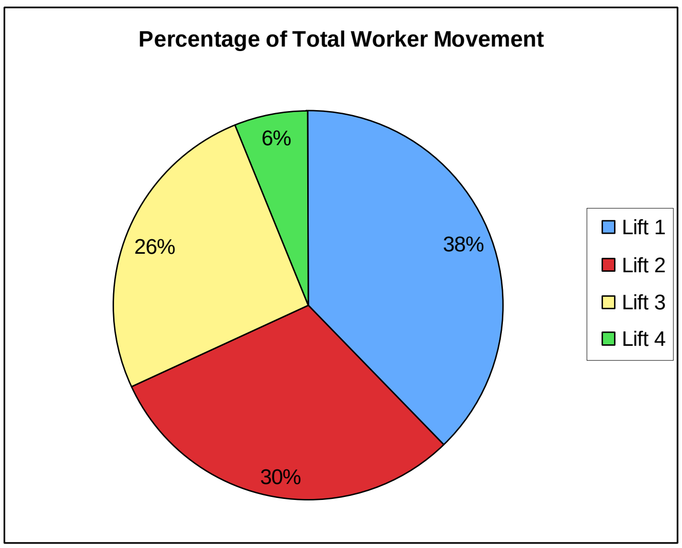


Figure 4.14: Percentage of Lift Use by Workers

It is evident from Figure 4.14 that Lift 1 was occupied by the most workers throughout the day at 38% of total lift use. The data shows that Skanska used the lifts far more than Harmon employees throughout the day. This can be explained by the nature of work conducted by Harmon employees. For example, because the latest shipment of glass already reached the installation floor on the day it arrived, Harmon employees were able to remain in one location to install the glass. Thus the need for employing their lifts was no longer necessary. Meanwhile, Skanska employees continuously travel throughout the site moving materials, clearing trash, and performing other necessary tasks. Several observations were made including seeing multiple instances when both Lifts 3 and 4 would be located on one of the upper floors of the building when a worker would arrive to the platform on the 16th floor in need of a ride. It would take nearly three minutes for the lift to return to the platform to pick up the worker and then another three minutes for it to travel back to the desired level more than sixty stories high. In order to improve this inefficiency, a number of Skanska workers were given two-way radios to alert the lift operators of need for transport. However, most instances included a worker without the aid of a radio causing him to wait for extended periods of time for the hoist operator to return.

Table 4.1 Lift Travel Times

Lift Travel Times Sample		
Start	**End**	**Time Duration (min)**
Street	16th Floor Platform	0:41
16th Floor Platform	Floor 64	2:56
16th Floor Platform	Floor 63	2:53
16th Floor Platform	Floor 62	2:50
16th Floor Platform	Floor 61	2:46
16th Floor Platform	Floor 60	2:42
Street	Floor 64	3:47+
Street	Floor 63	3:44+
Street	Floor 62	3:41+
Street	Floor 61	3:38+
Street	Floor 60	3:34+

Table 4.1 shows the travel times for lifts from the time it leaves the street or platform to the time it reaches its destination. Due to the nature of work tasks occurring within sets

of five floors at a time, the duration of travel times is consistent as there is no need for the lift operator to make multiple stops unless moving from one upper floor such as the 68th floor to the 67th floor. However, the travel time from the street to one of the upper floors relies on the availability of Lifts 3 and 4 upon a worker's arrival to the platform. This information is denoted with a "+" following the listed time. For example, it would take a worker at least 3 minutes 34 seconds to travel from the street level to the 64th floor but, as often is the case, there is additional time spent waiting on the 16th floor platform for an available lift to reach the top. This wait time depends on the availability and efficiency of the hoist operators.

The glass replacement schedule created by higher level management from Skanska and Harmon calls for the opening of a new buffer zone every 3 to 5 days with the expectation of replacing seventy-eight windows in a 3 day period. This necessitates roughly twenty-five to twenty-seven windows being replaced per day. Table 4.2 shown above lists the early operation date and finish date for each floor during the two week period of data collection. In addition, the expected date for glass arrival for each floor is shown along with the date the glass actually arrived.

Table 4.2 Floor Operations and Glass Arrival Schedule

Floor Number	Description	Early Operation Date	Early Finish Date	Total Work Days	Glass Arrival Schedule	Actual Glass Arrival
63	Buffer	2/3/2010	2/5/2010	3		
63	Operation	2/8/2010	2/18/2010	11	2/9/2010	2/10/2010
63	Buffer	2/19/2010	2/23/2010	5		
62	Buffer	2/8/2010	2/10/2010	3		
62	Operation	2/11/2010	2/23/2010	13	2/12/2010	2/12/2010
62	Buffer	2/24/2010	2/26/2010	3		
61	Buffer	2/11/2010	2/15/2010	5		
61	Operation	2/16/2010	2/26/2010	11	2/17/2010	2/19/2010
61	Buffer	3/1/2010	3/3/2010	3		
60	Buffer	2/16/2010	2/18/2010	3		
60	Operation	2/19/2010	3/3/2010	13	2/22/2010	2/22/2010
60	Buffer	3/4/2010	3/8/2010	5		
59	Buffer	2/19/2010	2/23/2010	5		
59	Operation	2/24/2010	3/8/2010	13	3/3/2010	3/2/2010
59	Buffer	3/9/2010	3/11/2010	3		

This sample data consisting of work for five different floor levels shows that two of the shipments of glass arrived one day late. Under normal circumstances work progress would be delayed as workers would have no materials to use to complete their tasks. However, through sufficient pre-planning, Skanska and Harmon have created a plan in which the windows are simply stored on the desired floor level for several days before the actual installation takes place. As seen in the table, the expected glass arrival date is always planned for one day after early operation on a new floor. This is due to the need for workers to prepare each floor for construction by moving furniture and other items away from obstruction and laying protective coverings over walls and carpet. Thus any delay in the shipment of glass fails to affect labor productivity.

4.3.2 Automated Analysis of Productivity

While visually observing productivity can produce results regarding the number of lift operations on a normal workday, having an automatic filter for data serves a greater purpose. The benefit of employing RFID in productivity analysis is its ability to track all data related to materials, workers, and lifts simultaneously. This data can be sorted and placed into a filter to determine important productivity information including the average time needed for people or materials to reach their destination along with the amount of time spent waiting for the lift to arrive. This data is difficult to record manually unless multiple people are available to track time-specific data for each item which increases costs as additional personnel is required for such a task. Table 4.3 shows time data for one individual worker over the course of one day. The buck hoist operator was chosen for analysis here to determine whether the lift is sufficiently available over the course of the day for workers to use. By tracking and analyzing the operator, the data can be viewed to determine how much time he spent waiting in certain locations before a different worker arrived to be transported.

Table 4.3 RFID Time Analysis

Data for Greg Williams 7:00 AM to 4:00 PM on February 25th				
Trade: Buckhoist Operator for Lift 3				
Platform to 60 Time	**Platform to 61 Time**	**Platform to 62 Time**	**16th Floor Wait Time**	**Top Floors Wait Time**
0:02:37	0:03:38	0:03:32	0:03:29	0:00:20
0:03:16	0:03:41	0:04:10	0:11:49	0:19:21
0:02:36	0:03:51	0:02:55	0:58:48	0:00:20
0:03:21	0:03:21	0:04:13	0:06:05	0:24:00
0:02:26	0:02:33	0:03:20	0:00:07	0:07:24
0:03:23	0:03:54	0:03:31	0:02:54	0:00:17
0:02:39	0:03:33	0:03:56	0:03:31	0:02:26
0:02:58	0:02:39	0:03:35	0:00:39	0:04:03
0:02:48	0:03:32	0:02:59	0:01:08	0:00:22
0:03:03	0:03:28	0:03:21	0:01:06	0:00:28
0:03:34		0:03:56	0:01:14	0:00:38
0:03:49			0:03:05	0:00:22
0:03:47			0:00:00	0:00:22
0:03:42			0:00:53	0:00:35
0:03:45			0:10:35	0:01:47
0:02:32			0:19:49	0:01:31
0:02:57			0:02:38	0:02:01
0:02:55			0:00:00	0:00:55
0:03:50			0:03:51	0:00:32
0:03:39			0:00:00	0:00:40
0:03:13			0:00:00	0:05:40
0:03:44			0:00:00	0:00:23
0:03:51			0:00:00	0:00:22
0:03:38			0:00:00	0:01:12
0:03:51			0:00:11	0:00:17
0:03:54			0:07:02	0:06:23
0:03:51				0:00:27
0:03:22				0:03:26
0:03:39				0:00:25
				0:00:00
				0:05:53
				0:00:55
				0:01:17
				0:00:23
				0:00:13
				0:01:53
				0:01:54
				0:00:31
				0:00:06
				0:01:45
				0:00:13
Average Time Totals:				
0:03:20	0:03:25	0:03:35	0:05:21	0:02:29

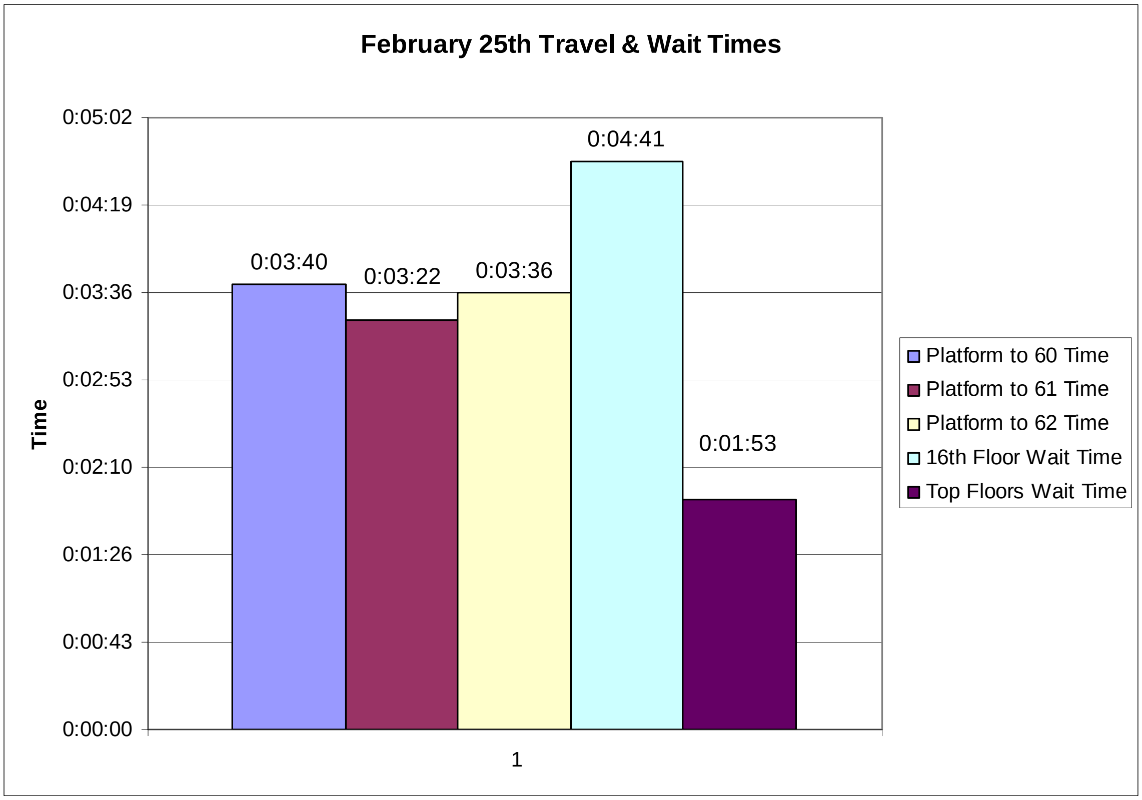


Figure 4.15 Average Travel and Wait Time Comparison

Based on the data shown in the table above, one can see that the average lift travel times to floors 60, 61, and 62 were longer than the manually recorded travel times. This most likely can be attributed to the operator slowing his productivity for socializing or personal purposes before activating the lift. For example, Table 4.2 shows that the manually recorded travel time from the platform to the 60th floor takes 2 minutes 42 seconds. However, the average time showed for the same distance in Table 4.3 is 3 minutes and 20 seconds. This time is calculated from the last moment the operator's tag was read on the platform, the moment he closes the safety door to the lift, to the first moment he opened the door to the lift at the 60th floor. Although the time difference of 38 seconds appears small, this wasted time accumulates over the course of the work schedule and impacts the labor productivity of other workers attempting to reach their specific work locations.

Table 4.3 also shows the average amount of time the operator remained in one location before utilizing the lift again. At the platform, the average wait time was calculated to be 5 minutes and 21 seconds showing that lift availability when stationed at the platform is more than adequate. Thus the need to employ an additional operator is excessive and would add unnecessary additional costs. Furthermore, the average wait time of the lift when stationed at the upper floors is 2 minutes and 29 seconds proving that the lift system for transportation purposes is adequate. Without the addition of RFID technology, it would have appeared as though workers were losing valuable time while waiting for the lifts which is incorrect and attributed to the difficulty of tracking productivity data manually.

More extensive RFID implementation throughout the site would have increased productivity results as the glass replacement process would be tracked and updated in real-time. Currently, each piece of glass is given a bar code which must be scanned manually to record the installation of the window. However, the use of a portable RFID reader would allow a worker to simply walk into a room with the reader to obtain the tags of the windows already installed in order to determine whether all of the tasks have been completed or more work is needed. RFID would save countless labor hours as the current bar code system forces a worker to check each individual room and piece of glass within the seventy-three floors of the project.

4.4 Factors Affecting Labor Productivity

In a project with multiple floors requiring the same work requirements, various factors are unable to be accounted for despite adequate planning. The data acquired in this research began after workers were able to become accustomed to the routine of the work from the four floors completed prior to data collection. Therefore, a level of comfort had been established in which untimely issues that had the potential to slow progress were handled and avoided later. The main factor that contributed to a loss of productivity in this research was the extreme weather conditions that existed during the data collection period. Mohamed (2005) identifies that severe weather including heavy rain or snow causes work progress to slow or even stop. Also, the thermal environment variations from air temperature, humidity, and wind velocity affect work efficiency and reduce productivity. In terms of this research, the location of the buck hoist system on the exterior of the building made it susceptible to the thermal environment. It was determined by upper management that any wind in excess of 25 miles per hour would stop all use of the material lifts and halt glass replacement.

Table 4.4 Daily Weather Conditions during Construction

Date	Day	Overview	Condition	Temperature	Precipitation	Humidity	Wind
2/22/2010	Monday	Cloudy	Wet	55	60%	91%	3 mph
2/23/2010	Tuesday	Cloudy	Dry	45	45%	70%	10 mph
2/24/2010	Wednesday	Cloudy	Dry	38	40%	75%	11 mph
2/25/2010	Thursday	Sunny	Dry	35	0%	43%	26 mph
2/26/2010	Friday	Sunny	Dry	40	0%	55%	17 mph
2/27/2010	Saturday	Sunny	Dry	50	20%	50%	12 mph
2/28/2010	Sunday						
3/1/2010	Monday	Sunny	Dry	48	20%	65%	5 mph
3/2/2010	Tuesday	Snow	Wet	34	100%	92%	20 mph
3/3/2010	Wednesday	Sunny	Dry	43	20%	66%	25 mph
3/4/2010	Thursday	Sunny	Dry	50	10%	40%	15 mph
3/5/2010	Friday	Sunny	Dry	49	0%	31%	27 mph
3/6/2010	Saturday	Sunny	Dry	55	10%	20%	10 mph

Based on Table 4.4, one can observe that February 25th, March 3rd, and March 5th experienced high winds causing the shut-down of all four lifts. In this instance, workers that are able to continue performing indoor tasks such as laying carpet and wall protection are forced to make use of the two service elevators located in the interior of the Westin. The service elevators prove especially inefficient as 15 sample wait times were recorded at the 16th floor and showed an average wait of 3 minutes 24 seconds. Even with the arrival of an elevator, more time is lost as Westin employees continuously use the elevators to reach their desired destinations.

Another weather issue that results in less productivity is rain. Rainy weather is listed in the table as “wet” within the Condition column and usually ends the workday or forces workers to stop until conditions improve. The site superintendant checks weather conditions for potential rain or high winds each morning and then every 30 minutes after the day begins to prepare for poor weather conditions. Lost workdays during the week are salvaged by opening the site for construction on Saturdays.

Other environmental aspects such as temperature and humidity play a role in labor productivity as well. Humans work most effectively when temperatures fall within the range of 50 and 70 degrees Fahrenheit and humidity is between 30 to 80 percent (Oglesby 1988). Table 4.3 shows that 8 of 12 data collection days had temperature outside of the optimal range while humidity was a factor during two of those days. Due to the timing of the experiment taking place in February, the cold temperatures caused workers to take frequent breaks to warm their hands for equipment-related tasks. The excessive winds at the upper floors of the Westin intensified the effects of the low temperatures. Although each worker is equipped with thick gloves to provide some comfort, these sometimes hamper productivity when the task requires meticulous work.

Producing a weather table within the database and creating a relationship to the data gathered from the RFID allows employees to get a sense of why work on a particular day progressed at a faster or slower rate.

4.5 Worker Evaluation

An evaluation of the worker's reaction to the technology was performed during the initial stage of RFID deployment and throughout data collection. Interviews were conducted with each worker who was given an RFID tag to discover the benefits and concerns of tracking labor productivity in a construction project. In addition, it enabled workers to voice there opinions and possible ideas on the use of radio-frequency technology on-site in terms of productivity. Receiving worker feedback helps find strengths and weaknesses associated to the use of RFID technology and generates suggestions for improvements in the system. The interviews made clear the amount of comfort the workers have with being tracked, how much monitoring they are comfortable with, and how they feel about the proposed technology's future in the industry. The interviews will determine if workers think pro-active-real-time personnel warning system will make a difference, and if they think the PPU is a comfortable, good style of protection device. At the conclusion of the project, an impact analysis of the technology on productivity and safety will be evaluated along with a cost-benefit analysis. While it is difficult to specify the value of individual workers, insurance costs, time lost due to work inefficiencies, and safety costs will be taken into consideration against the cost of implementing a RFID system to track various component of a construction project.

4.6 Sources of Error in Data Collection

There are several sources of error related to data collection. In this particular construction project, workers were unaware of the use of RFID technology when they signed their work contracts. Therefore, workers were able to reject being given unique passive tags and avoid contributing to the research effort. One Harmon employee explained a fear that “the tags may cause cancer or produce headaches” whiles another member of Skanska was simply uncomfortable with being tracked at all times. Along with not receiving data from every worker located on-site, several workers who accepted the tags initially where found to have removed the tags from their helmets. Another occasional interruption in data collection occurred when a worker disabled the data collection system on several instances by unplugging the power to the readers, router, and laptop. The system was reconnected each evening to begin collecting additional data the following morning. Despite these unfortunate occurrences, the technology was able to gather sufficient data for productivity analysis.

CHAPTER 5: FURTHER DEVELOPMENT

Future research should focus on automating the data transfer process from the jobsite to a database for analysis. This automation would allow workers to simply spend time ensuring that the technology is continuously running rather having to transfer and import data stored from text files into tables within the database. Although a slight majority of workers complied to requests of not tampering with the passive tags, future research should be conducted to prove that RFID tags embedded within the hard hat can still be read while also preventing workers from removing or damaging tags. In addition, research is needed to determine methods to increase worker involvement in analysis studies such as instructing foremen to support and advocate the use of the technology to workers. Researchers should seek to increase the signal transmission range of the readers or simply test multiple RFID to find the most appropriate for material tracking purposes over longer distances.

CHAPTER 6: CONCLUSION

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 this technology can be successfully implemented and used to record important data within an indoor construction environment despite the vast height of the structure and the presence of concrete and metallic elements for the purpose of labor productivity analysis. 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 other automated position-tracking technologies are limited by various drawbacks and thus insufficient for productivity analysis purposes. However, the implementation of RFID can greatly improve the accuracy of productivity analysis with the use of a database while also saving staff members excessive amounts of time filing through manually recorded data. In fact, the use of RFID can reduce a construction company's costs related to productivity analysis simply by negating the need for multiple workers to collect and record data. The analysis conducted in this research shows 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. Unless a team of multiple people was employed for data recording, manual analysis through visual observations would have incorrectly shown that workers were losing valuable time while waiting for the lift to arrive. However, data produced from RFID technology shows that lift availability is more than adequate at the Westin high-rise construction site.

REFERENCES

AlimakHek Group. <http://www.alimakhek.com> (Accessed January 21, 2010).

Atlas RFID Solutions. Alabama Chapter. http://www.atlasRFIDsolutions.com (Accessed January 13, 2010).

Center to Protect Workers' Rights (2002). *The Construction Chart Book* (3rd edition). Silver Spring, MD: Author.

Center for Construction Research and Training (2006). "Deaths and injuries involving elevators and escalators." <http://www.elcosh.org/en/document/405/d000397/deaths-and-injuries-involving-elevators-and-escalators-a-report-of-the-center-to-protect-workers-rights.html#1> (Accessed February 3, 2010).

Chang-Yeon, Cho et al. (2009). Basic study of smart robotic construction lifts for increasing resource lifting efficiency in high-rise building construction. *26th International Symposium on Automation and Robotics in Construction (ISARC 2009).* 266-277.

Ergen, E. Akinci,, B. East, B. Kirby, J. 2007. "Tracking components and maintenance history within a facility utilizing radio frequency identification technology." *Journal of Computing in Civil Engineering*. 21, 11-20.

Everett, John. Slocum, Alexander. (1993). "CRANIUM: device for improving crane productivity and safety." *Journal of Construction Engineering and Management,* 119, 23-39.

Grau, David et al. (2009). “Assessing the impact of materials tracking technologies on construction craft productivity.” *Automation in Construction*. 18, 903-911.

Goodrum, P. McLaren, M. Durfee. A. 2006. “The application of active radio frequency identification technology for tool tracking on construction job sites.” *Automation in Construction*. 15, 292-302.

Hendrickson, Chris. (2008). Project Management for Construction. <http://pmbook.ce.cmu.edu/> (Accessed January 27, 2009).

Ichniowski, Tom. Van Hamption, Tudor. (2009). “Construction deaths decline sharply.” August, 31. http://enr.ecnext.com/coms2/article_bmsh090826Construction. (Accessed December 21, 2009).

Khoury, Hiam. Kamat, V.R. (2009). “Evaluation of position tracking technologies for user localization in indoor construction environments.” *Automation in Construction.* 18. 444-457.

Khoury, Hiam. Kamat, V.R. (2008). Indoor user localization for rapid information access and retrieval on construction sites, Proceedings of the 15th Workshop of Intelligent Computing in Engineering and architecture, Plymouth, UK, 2008.

Lee, Ghang et al. (2009). “A laser-technology-based lifting-path tracking system for a robotic total station.” *Automation in Construction*, 18, 865-874.

Lee, J.B. et al (2008). “A feasibility study on optimal lifting planning in the high-rise apartment building construction.” *Journal of Korea Institute of Construction Engineering and Management Institute*, 9, 185-193.

Lee, Ung-Kyun et al (2006). Improving tower crane productivity using wireless technology. *Computer-Aided Civil and Infrastructure Engineering*, 21, 594-604.

McCann, M. (2003). Death from falls in construction. *Journal of Safety Research,* 34, 507-514.

Mohamed, Sherif. Srinavin, Korb. (2005). "Forecasting labor productivity changes in construction using the PMV index." *International Journal of Industrial Ergonomics,* 35, 345-351.

Oglesby, Clarkson. (1988). "Productivity Improvement in Construction." McGraw-Hill Series in Construction Engineering and Project Management, 146-271.

Pan, Christopher. (2007). Aerial lift fall injuries: A surveillance and evaluation approach for targeting prevention activities. *Journal of Safety Research*, 38, 617-625.

Perttula, Pia et al. (2006). Improving the safety and efficiency of materials transfer at a construction site by using an elevator. *Journal of Construction Engineering and Management,* 836-843.

"Review of the current state of Radio Frequency Identification (RFID) Technology, its use and potential future use in construction." Erabuild Final Report. (December 2006)

Ross, W. Burns, S. Wu, Jared. 2009. "Radio frequency identification tracking technology applied to testing of transportation construction materials." Journal of Transportation Research Board No. 2098, 3-12.

Sams, Douglas. (2009, August 28). Storm-torn Westin to be reborn. *Atlanta Business Chronicle.*

Wang, Lung-Chuang. (2008). Enhancing construction quality inspection and management using RFID technology. *Automation in Construction*, 17, 467-479.

APPENDIX A: SKANSKA USA BLDG INC. CONSTRUCTION SCHEDULE

Skanska and Harmon met together with the intention of producing a work schedule since the tasks of each company rely greatly on each other's rate of progress. This schedule is updated whenever it appears as though progress is ahead or behind the original schedule. Figures A.1-4 correspond to the schedule that was updated on January 27, 2010 which is four pages in length. Figure A.5 shows the weekly work schedule that was created on January 28th.

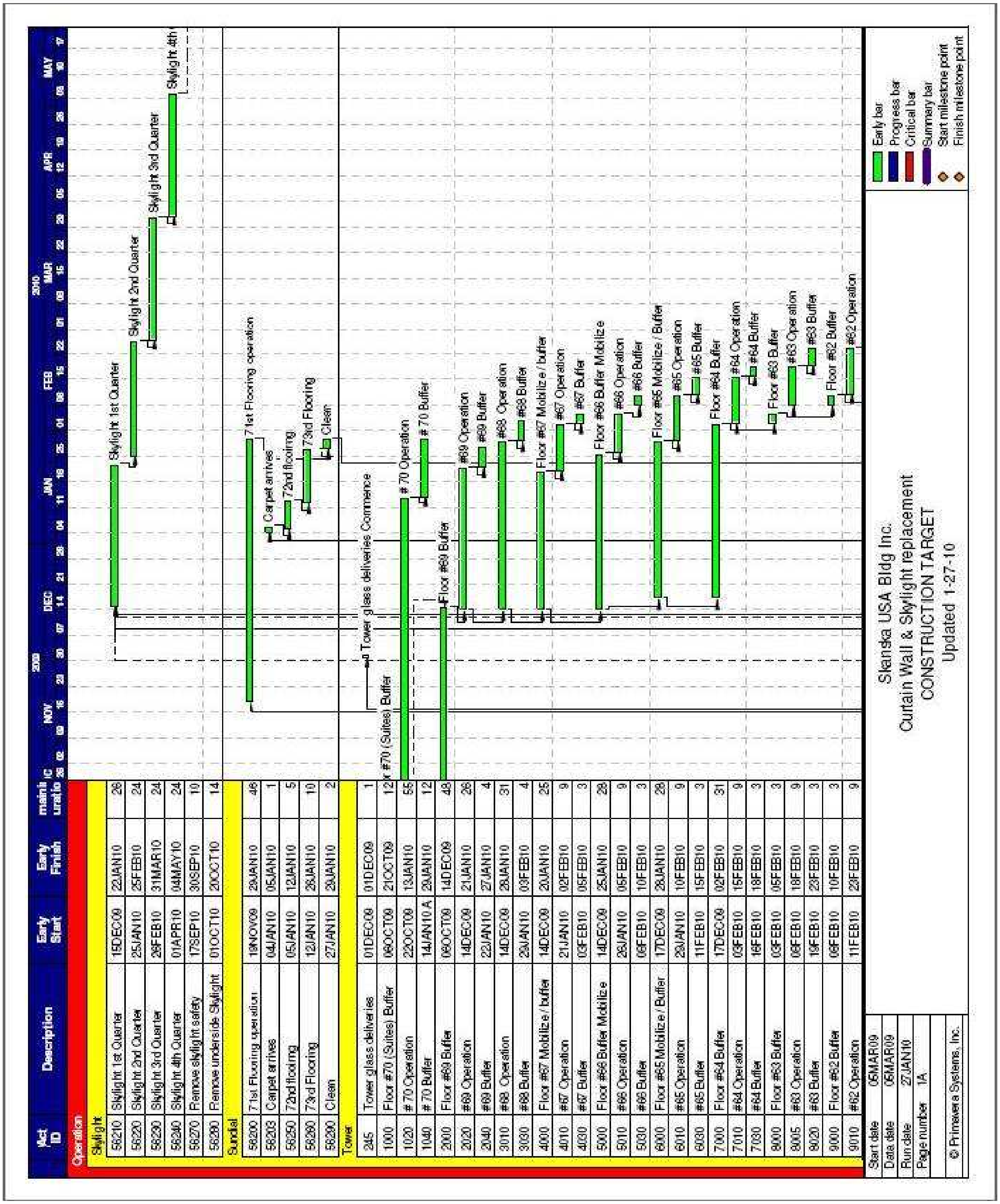


Figure A.1: Skanska Construction Target (Page 1 of 4)

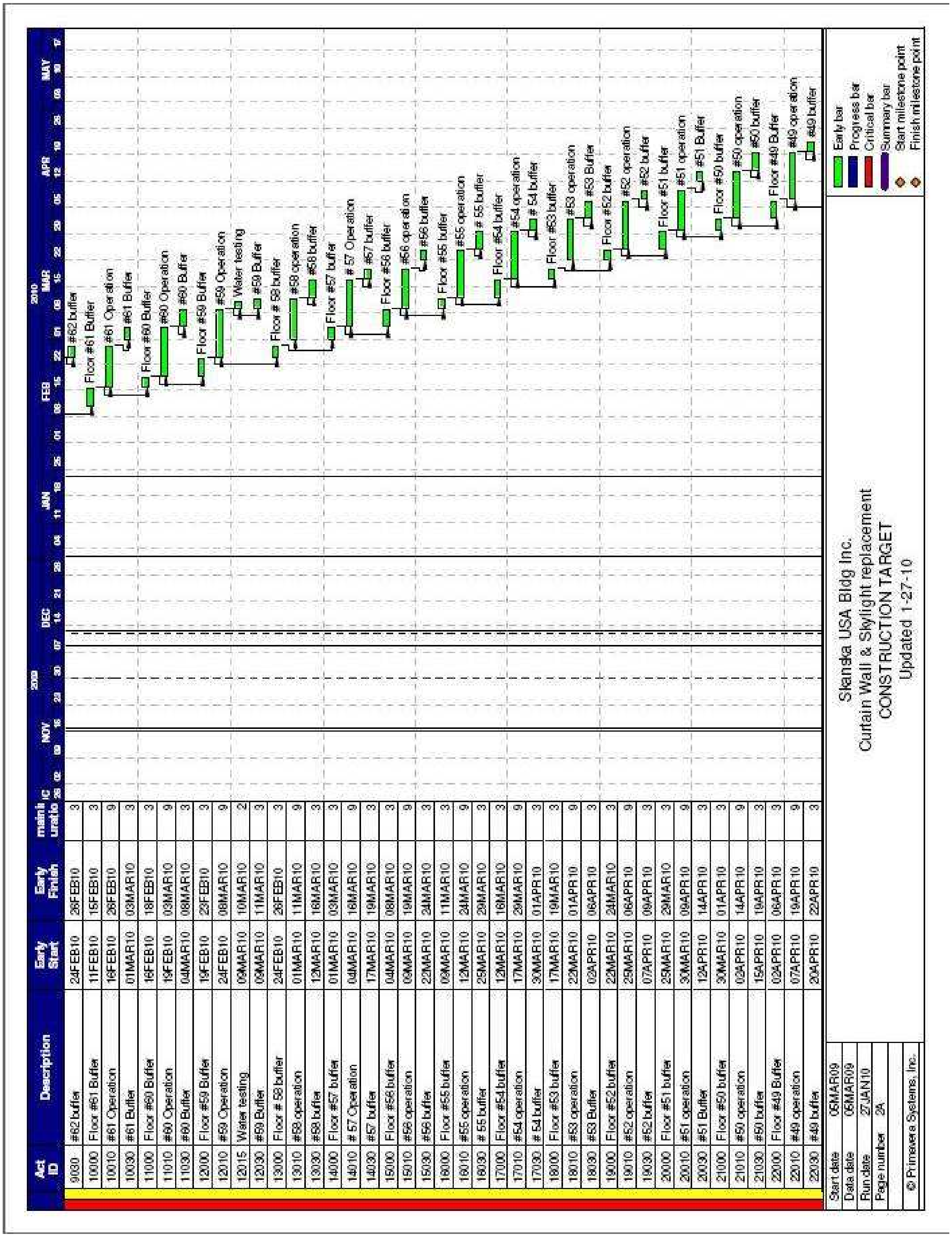


Figure A.2: Skanska Construction Target (Page 2 of 4)

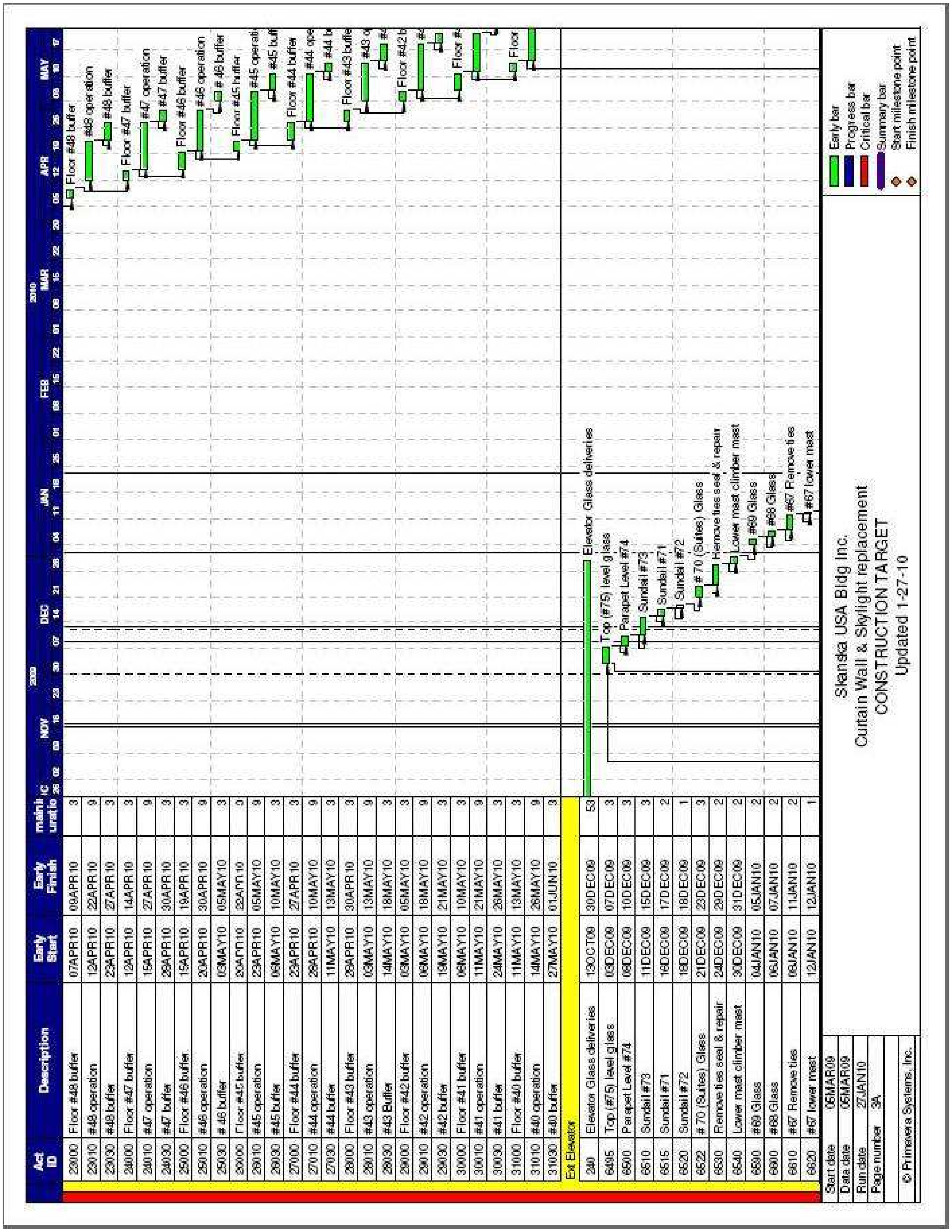


Figure A.3: Skanska Construction Target (Page 3 of 4)

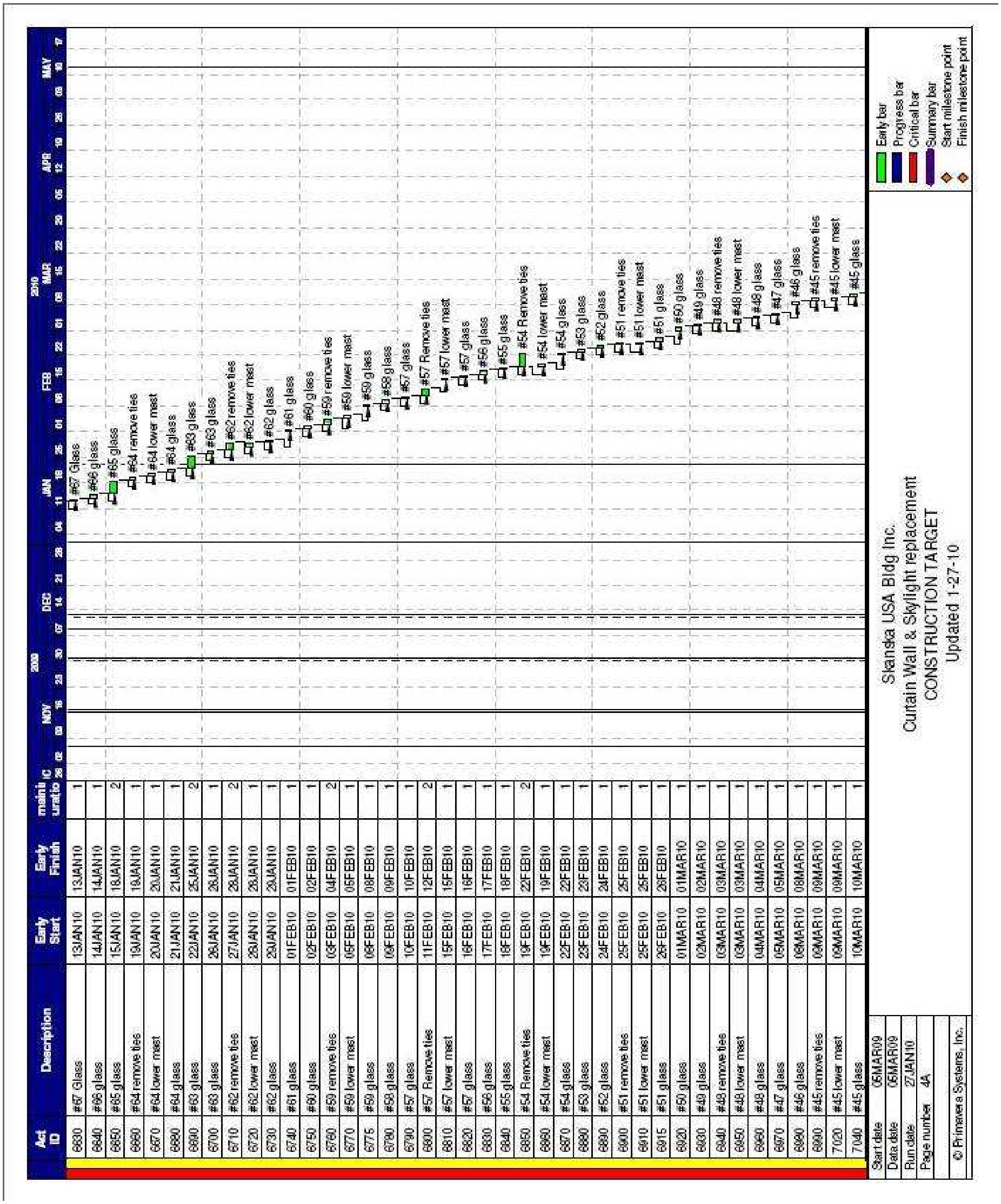


Figure A.4: Skanska Construction Target (Page 4 of 4)

SKANSKA

Westin Hotel Curtain Wall & Skylight replacement project — **Weekly Update: 1-28-10**

No.	Summary Desc.		Full Description	Action	
	Submittals	1/28/10	Internal elevator shop drawings and meeting rooms	Sent 1-20-10	
			Comments to returned calcs	Approved 1-26-10	
			Manufacturers observation report - Bruce Wall	Sent 1-19-10	
			Skylight expansion joint data	Sent 1-19-10	
			Submittal log with list of items remaining for verification	Sent 1-18-10	
	Hoist & mastclimbers	1/28/10	Mastclimbers are being dropped to move from below swing stage that services floors.		
		1/21/10	Glass to window at 71 where MC #1 is located has arrived on site, this will allow this mast climber to be dropped		
			Hoist has been removed from Sundial, though is still tied into 69 for guest room operation		
			Hoist will remain at 69 until floors 65 completed		
		1/6/10	Hoist 3 will be removed from Sundial on Monday 11th Jan		
			Mastclimbers #1 has been dropped, #2 & #3 to be below Sundial WC 1-11-09		
	General items	1/28/10	Sundial reset has commenced		
		1/28/10	Cleaning to the Sundial ext has been completed		
			The new Reinforced safety netting has been installed		
			Nozzle test to parapet complete no issues.		
			Re-placement netting on site and installed over West elevation of Skylight		
		1/6/10	New replacement netting on site, will be attached and recabled commencing 1-6-09		
	Sundial	1/28/10	All trim has been completed (except missing stops)		
			Carpet complete		
			Wheels and welding complete		
			Booths and furniture in process of being put back		
			Punchwalks have been carried out, as of yesterday 95% completed		
		1/21/10	Carpet has been completed, Turntable has been rotated, internal cleaning ongoing		
			Available for punchwalk 1-22-10		
			Granite tile in progress of being installed		
		1/14/10	Glazing complete, hoist removed. Carpet to 72, 71 and 73 continues.		
			Welding complete, wheels complete though Drive wheels are not on site due 15th Dec		
			Cleaning to internal areas progressing (Windows to wall) - upper internal windows in progress		
		1/6/10	Glazing 99% complete, remaining are the panes at the Buck hoist location		
			Flooring is progressing level# 72 has been removed, #73 will be removed after Jan 8th Function,		
			Wheels are on site and are being installed, wood flooring continues		
			Carpet to be delivered 1-6-10		
	Skylight	1/28/10	122 pieces installed to date		
			Quad 2 completely measured, remaining glass will be installed next week, Quad one has been measured also		
		1/20/10	Glass delivery this week		
			Quadrant One has been measured, glass delivery due 1-18-10		
		1/6/10	96 pieces have been installed to date		
			56 are in process of measurement for next glass shipments		
	Scenic Elevator	1/28/10	Glass has been installed down thru Fl 61		
		1/20/10	Replacement panel at 71 has arrived, MC will be dropped to continue operation at 64 and down		
		1/14/10	Glass has been installed down to level 65		
		1/6/10	Glass has been installed thru 70th level, operation concentrating on removing ties and dropping MC #2 & #3		
	Guest rooms	1/28/10	Flr 70 is open to Hotel		
			Flr 69 due to be completed today		
			Flr 68 to be completed 2-3-10		
		1/21/10	Floor 68 glazing complete		
			Floor 67 glazing commenced		
			"put back" at floors 69 & 70 continues		
		1/14/10	Flr 70 glazing complete, trim in progress, rest for 1-18-10, OSE scheduled for 1-20-10		
			Flr 69 scheduled to be available for OSE 1-25-10		
			Flr 68 glazing commenced		
		1/6/10	99% of floor 70 installed, tentative operation to relocate furniture and items will be scheduled 1/14/10		
			50% glass on floors 69 installed		
6e	Glass count	1/21/10	Sundial	236	
			Parapet	79	
			Guestrooms	319	
			Scenic elevator	153	
			subtotal	787	
			Skylight	122	
			Total	909	
7	Short term		Require Floor 63 to be released 2-3-10		
				Sat Make-up days	Weather delays
9	Weather	1/26/10	Activities suspended due to high winds	1	
		1/21/10	Rain	1	
		1/14/10	Coldweather and wind conditions have affected some aspects of the external operation.		0
		12/28/09	Winds		0.5
		12/18/09	Rain & wind		1
		12/10/09	Rain & wind		1
		12/9/09	Rain & wind		0.5
		12/8/09	Rain & wind		1
		12/7/09	Rain & wind		0.5
		12/2/09	Rain		1
		11/30/09	Rain - 1/2 day		0.5
		11/10/09	Heavy rain		1
		10/31/09	Heavy Rain - Weather affected day		1
		10/30/09	Heavy rain - 1/2 day		1
		10/27/09	Heavy Rain - Weather affected day		1
		10/12/09	Heavy Rain - Weather affected day		1
		10/5/09	Highwinds - no letter removal		
		9/29/09	Highwinds - no letter removal		1
		9/28/09	Highwinds - no letter removal		1

Figure A.5: Skanska Weekly Schedule from January 28th